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TWO BABYLONIAN ECLIPSES.

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With two exceptions the recorded times of ancient eclipse observations are provokingly vague. Otherwise the time is only once expressed more definitely than to the nearest third of an hour ; * the interval separating the observation from sunset, from which the original measure of time was normally made, is often long, and the observed time may therefore be affected by a large clock-error ; and if this interval is long there is room for the additional error arising from the conversion of time from one system of reckoning to another.† What is wanted is an eclipse observed close to sunset, and with the interval separating the observation from sunset expressed in small units of time.

Only two such eclipses are known to me. But two accurately timed observations may be of more value than a long series of vaguely timed observations.

Eclipse of the Sun, −321 September 26

Of these two one is a solar eclipse mentioned in Kugler's *Sternkunde und Sterndienst in Babel*, Buch II, 385, 1924, cited from the unpublished British Museum tablet Sp. I. 192, Rs. 18, on which according to his statement, which Dr. Langdon has kindly verified, it is recorded that in the 2nd year of Philip, on the 28th day of Ulul, an eclipse of the Sun began 4 *UŠ* before sunset. The Babylonian date reduces to −321 September 26. The *UŠ* was the 360th part of day and night combined and was, therefore, equivalent to the time in which the Sun's hour-angle increases by one degree, or four

* Theon gave the observed times of the solar eclipse of +364 June 16 to the nearest sixth or fifth of an hour, but that eclipse was not near sunset. See *M.N.*, **81**, 114, 1920.

† See my communication, *The Observatory*, **55**, 340, 1932.

minutes of our time. The name *UŠ* is an ideogram, whose phonetic expression in Semitic Babylonian appears to be still unknown. According to M. Thureau-Dangin * it was read *geš* in Sumerian.

This record was used by Kugler in a study of the Babylonian calendar, but has not hitherto been applied to any astronomical purpose. As it is the most precisely timed of all ancient observations of eclipses, it is important that the observation should be compared with computation.

I learn from Dr. Langdon that the Spartola collection to which the tablet belongs is believed to come from Sippara, the Sepharvaim of the Old Testament, longitude 44° 17′ E., latitude 33° 5′ N.

For the time of sunset, I find the Sun's right ascension and declination from Neugebauer's *Tafeln zur astronomischen Chronologie*, ii, 1914, with the corrections contained in his *Astronomische Chronologie*, ii, 1929. I take 90° 50′·5 as the true zenith distance of the Sun's centre at sunset, and compute the time of sunset trigonometrically. I thus obtain for the hour-angle of sunset at Sippara 91°·4.

For the time of the eclipse I use Schoch's *Neubearbeitung der Syzygientafeln von Oppolzer*,† with a correction to the longitude of the Moon's node supplied to me in MS. by Schoch in 1929 shortly before his death.

The elements thus corrected are :

Moon :

$$\begin{array}{lrrrrrr} & ^\circ & ' & '' & '' & '' & '' \\ L & 335 & 43 & 25{\cdot}68 & +1732564392{\cdot}34T & +12{\cdot}036T^2 & +0{\cdot}0089T^3 \\ \Pi & 225 & 23 & 50{\cdot}12 & +14648592{\cdot}31T & -37{\cdot}061T^2 & -0{\cdot}0440T^3 \\ \Omega & 33 & 16 & 16{\cdot}43 & -6962909{\cdot}51T & +7{\cdot}509T^2 & +0{\cdot}0095T^3 \end{array}$$

Sun :

$$\begin{array}{lrrrrrr} L' & 279 & 54 & 49{\cdot}52 & +129602764{\cdot}81T & +2{\cdot}473T^2 & \\ \Pi' & 279 & 30 & 11{\cdot}95 & +6180{\cdot}79T & +1{\cdot}578T^2 & +0{\cdot}0100T^3 \\ \epsilon & 23 & 27 & 55{\cdot}39 & -47{\cdot}07T & -0{\cdot}012T^2 & +0{\cdot}0018T^3, \end{array}$$

where T is the number of Julian centuries elapsed since 1800 January 0, Greenwich mean noon.

Schoch's tables include in the longitude of the Sun the long-period term of

$$+6''{\cdot}40 \sin (211^\circ{\cdot}0 + 20^\circ{\cdot}20T),$$

and in the longitude of the Moon the Venus term of

$$+14''{\cdot}44 \sin (213^\circ{\cdot}7 + 132^\circ{\cdot}86T),$$

and the great empirical term of

$$+13''{\cdot}92 \sin (103^\circ{\cdot}9 + 138^\circ{\cdot}0T).$$

For the lunar semi-diameter he adopted

$$0{\cdot}272274 \sin \pi.$$

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* *Esquisse d'une histoire du système sexagésimal*, 42, 1932.

† *Mitteilungen des astronomischen Recheninstituts Berlin-Dahlem*, Band 2, Nr. 2, 1928.

Otherwise the inequalities are the same as in Oppolzer's *Syzygientafeln*,* and the computation proceeds by means of the tables printed on pp. [24]–[50] of that work with the aid of the formulæ given on pp. [50]–[52], so far as these are not superseded by simpler formulæ given by Schoch.

I thus obtain the arguments :

I	II	III	IV	V	VI	VII	VIII	τ
214·25	330·07	395·7	284·2	144·3	3	98	359	0·204

which have the same meaning as in Oppolzer's tables, and the elements :

Date	−321 September 26	$\log \Delta L$	9·7008	K	90°·36
U.T. of conjunction,	$14^h\ 19^m\cdot1$	$\log q$	8·7062	$\log \sin g$	9·6924
L'	178°·426	$u'a$	0·5722	$\log \sin k$	9·9397
Z	−1°·74	$\log f_a$	7·6733	$\log \cos g$	9·9397
ϵ	23°·739	μ	37°·73	$\log \cos k$	9_n6923
P	175°·818	γ	+0·4022	$\log \sin \delta'$	8·0434
Q	176°·32	$\log n$	9·7029	$\log \cos \delta'$	0·0000
$\log p$	0·7438	G	178°·88	N'	119°·5

From these I obtain for the Sun's hour-angle at first contact 86°·59. The observed time, as has been seen, implies an hour-angle of 91°·4 − 4° or 87°·4. The observed correction to the tabular time is therefore +0·8 *UŠ* or +3 minutes.

I now apply a correction of −100″ to the Moon's mean longitude, leaving the Sun's position unchanged. Making the necessary corrections in the computation, I find that the tabular hour-angle of the Sun at first contact becomes 87°·41, so that the observed correction to the time is equivalent to a correction of −100″ to the tabular mean longitude of the Moon, or rather to the difference between the mean longitudes of Moon and Sun, on which the time depends.

Again, leaving the original tabular mean longitudes of Moon and Sun unchanged, I apply a correction of −100″ to the longitude of the Moon's node. This gives 86°·69 as the Sun's hour-angle at first contact, a correction of only +0°·10 to the tabular hour-angle. From this it follows that a correction to the difference in longitude of Sun and node has only one-eighth of the effect of a correction of equal amount to the difference in longitude of Sun and Moon. We may conclude, therefore, that the observation tells us nothing as to the accuracy of the tabular difference in longitude of Sun and node, but gives the small correction of −100″ to the difference in longitude of Sun and Moon. Even this correction is wholly doubtful, because the error in time from which it is deduced is less than the unit of measurement.

Eclipse of the Moon, −424 *October* 9

With the solar eclipse I compare an eclipse of the Moon recorded on the tablet CBS 11901 in the Museum of the University of Pennsylvania. This tablet was published with full text, translation and commentary, accompanied by a photographic reproduction of the original by Dr. Weidner

* *Publication der astronomischen Gesellschaft*, xvi, 1881.

in *Alter und Bedeutung der babylonischen Astronomie und Astrallehre*, 1914. It contains among other astronomical observations a record of an eclipse of the Moon which began 10 *UŠ* after sunset on the 15th of Tešrit. The name of the year has not been preserved. Dr. Weidner recognised that it was an observation tablet, but he and Professor Neugebauer, whose aid he sought, failed to date it. Kugler in *Sternkunde und Sterndienst in Babel, Ergänzungen* 233–242, 1914, gave a full transliteration and translation of the text, and showed that the phenomena belonged to the year −424, and that the lunar eclipse was that of October 9 in that year, but he unfortunately mistook the document for an ephemeris. Schoch corrected Kugler's error in his paper, *Die säkulare Acceleration des Mondes und der Sonne*, published in Selbstverlag, 1926, and reprinted in *Astronomische Abhandlungen, Ergänzungshefte zu den Astronomischen Nachrichten*, Band 8, Nr. 2, 1930. The grounds on which he established that the document was an observation text were given more fully by me in *The Venus Tablets of Ammizaduga*, 50, 1928. Meanwhile I had drawn attention to Schoch's result in *M.N.*, **87**, 154, 1926; **87**, 184, 1927, and the eclipse was used along with other evidence by De Sitter in a determination of the secular acceleration of the Moon's mean motion.* The tablet comes from Nippur, longitude 45° 11′ E., latitude 32° 6′ N., but Kugler, Schoch and De Sitter appear to have computed for Babylon. The local time of the beginning of the eclipse would be nearly three minutes later at Nippur than at Babylon.

The hour-angle of sunset at Nippur computed as before from Neugebauer's tables was 88°·1 ; the middle of the eclipse computed by Schoch's tables was at $17^h\ 20^m{\cdot}9$ U.T., and the semi-duration was $110^m{\cdot}1$, giving $15^h\ 30^m{\cdot}8$ U.T. for the beginning. The hour-angle of the Sun at Nippur was 100°·5 at that time, comparing with an observed hour-angle of 98°·1. The observed correction to the tabular time is, therefore, −2°·4 *UŠ* or −10 minutes. This is equivalent to a correction of +300″ to the tabular difference between the mean longitudes of Moon and Sun.

Conclusions

It will be noticed that the two eclipses yield corrections in opposite directions, and that the two corrections are approximately in proportion to the observed interval before or after sunset. If, therefore, the eclipses are weighted in inverse proportion to this interval, the correction to Schoch's value for the difference between the mean longitudes of Moon and Sun becomes negligible.

It may be of interest to compare Schoch's last tabular value for the difference between the mean longitudes with those adopted by me in *M.N.*, **87**, 184, 185, 1927, and by De Sitter in *B.A.N.*, **130**, 70, 1927. The complete expressions are:

$$\Delta D \text{ (Schoch-Fotheringham)} = -0''{\cdot}92 + 1''{\cdot}17T + 0''{\cdot}103T^2 + 0''{\cdot}0021T^3$$
$$\Delta D \text{ (Schoch-De Sitter)} \quad = +0''{\cdot}39 - 0''{\cdot}81T + 0''{\cdot}153T^2 + 0''{\cdot}0021T^3$$

* *B.A.N.*, **124**, 22, 23, 36, 1927 ; **130**, 70, 1927.

The values of these expressions at the epochs of the two eclipses discussed in this paper are :

	−320·24	−423·20
ΔD (Schoch-Fotheringham)	+ 0″·56	+ 0″·90
ΔD (Schoch-De Sitter)	+66″·33	+70″·94

It will be seen that the differences between these solutions amount in each case to less than one *UŠ* in the tabular time of the eclipse, De Sitter's formula giving a slightly better result than Schoch's for the eclipse of −321, and a slightly worse result for the eclipse of −424.

The result of the new material is a very satisfactory confirmation of the recent determinations, which give a value of approximately +9″·5 per century to the difference in acceleration of Moon and Sun.

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Oxford :
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NOTE ON THE EQUATORIAL CURRENT OF JUPITER.

A. Stanley Williams.

This note is supplemental to the paper (referred to as the chief paper) published in the *Monthly Notices*, **94**, 240, 1934. For some time past the writer has been working up some of the earlier observations with the object of getting additional and better values of the rotation period of this current. This work, which is still in progress, has met with a certain amount of success. And the new results for the years 1881 to 1883 appear so remarkable that it seems desirable to put them on record without delay. The following is a short summary of the work so far as it has proceeded.

Opposition of 1892–93

In the course of this opposition the writer observed 1579 transits of spots on the planet, and the following determinations of rotation period have been made from the numerous observations and are considered to be reliable :—

S. Equat. Current. Rot. Per. $9^h\ 50^m\ 25^s{\cdot}35$ (28 spots) ; wt. 3.
N. ,, ,, ,, ,, $9^h\ 50^m\ 25^s{\cdot}34$ (19 spots) ; wt. 3.

The closeness of the two results is no doubt a coincidence, but the motion of the current was evidently nearly uniform throughout its whole width. Numerous dark spots on the equatorial band (in the middle of the Equatorial Zone) confirm this uniformity.

Opposition of 1882–83

The value given in Table I of the chief paper ($9^h\ 50^m\ 9^s{\cdot}7$) was derived from a single spot. This spot, a brilliant white one, had been followed assiduously by Denning between the years 1880 to 1884, so much so that it was quite commonly referred to as the Denning spot. It was therefore a great surprise when a complete reduction of all available observations yielded quite a different value of the rotation period of the S. Equat. Current as a whole. The material available for this opposition consisted of 55 transits recorded by Denning and about 220 by the writer, together with a few others (all of equatorial spots). Great help in making sure of the correct identification of the different spots was given by rough positions derived from the drawings of Jupiter made by Boeddicker at Lord Rosse's observatory with the three-foot reflector there.* But the actual determinations of rotation period depend entirely upon the central meridian transits alone. The following are the results obtained :—

S. Equat. Current. Rot. Per. $9^h\ 50^m\ 19^s{\cdot}9$ (20 spots) ; wt. 3.
N. ,, ,, ,, ,, $9^h\ 50^m\ 39^s{\cdot}2$ (17 spots) ; wt. 3.

The period of the S. Equatorial Current, as a whole, has therefore been increased from $9^s{\cdot}7$ to $19^s{\cdot}9$ (the relatively short period of the Denning spot being included in the latter value). The Denning spot may therefore be described as a runaway spot. And apparently it has been in existence as such for three or four years at least. This is a very remarkable circumstance. Both the relatively short period and the correct identification of the spot in the three or four years since 1880 are absolutely certain.

Opposition of 1881–82

The material for this opposition consisted of 61 transits of S. Equatorial spots † observed by Denning and 128 by the writer. There are also 50 determinations by G. W. Hough from his micrometric measures. In addition a great many rough positions were estimated from the drawings of Boeddicker, Niesten, Terby and others. These were only used for the purpose of identification. The actual rotation periods were computed from the transit observations and micrometric measures only. The following is the mean result :—

S. Equat. Current. Rot. Per. $9^h\ 50^m\ 24^s{\cdot}92$ (22 spots) ; wt. 3.

The value given in Table I of the chief paper is $9^h\ 50^m\ 09^s{\cdot}3$, so that here we have a still larger increase ($15^s{\cdot}6$). The Denning spot is still a runaway spot.

The values given above should be substituted for those of Tables I and II of the chief paper. The summary at the end of this paper also requires alteration, so as to read : "(3) Between 1881 and 1928 the rotation period

* See *J.B.A.A.*, 45, 199, 1935, for some remarks by the writer on these drawings.
† There are only a few observations relating to the N. Equat. Current.

of the S. Equatorial Current increased in length from $9^h\ 50^m\ 25^s$ to $9^h\ 50^m\ 45^s$, a difference of 20^s." * And if the new values are inserted in fig. 1 of the chief paper it will be seen that the early part of the velocity curve is greatly altered. Incidentally, the recent experience must be regarded as a caution against accepting a result based on only a restricted region of the planet as being representative of the whole current.

Polvarth, St. Mawes :
1935 *June* 10.

FLUORESCENCE PHENOMENA AND CENTRAL INTENSITIES IN FRAUNHOFER LINES.

A. Pannekoek.

1. The central intensity observed in absorption lines in stellar spectra has been for many years a puzzle for astrophysicists, since they could not be explained by the ordinary theory of the formation of absorption lines. In an important paper presented 1934 May to the Society, Dr. R. v. d. R. Woolley has shown that fluorescence phenomena, especially when produced by cyclical processes involving ionization, are able to account for appreciable central intensities in hydrogen lines. The importance of the result makes it desirable to discuss the phenomena due to such processes somewhat more in detail.

We will treat here the intensity in $H\alpha$ and $H\beta$, the same case as considered by Woolley, varying some of his notations and suppositions. Woolley introduces quantities $A_{23}\ \ldots\ A_{32}\ \ldots$ denoting the probability of transition 2–3 and 3–2 . . . ; then denoting by $A_{22} = -(A_{21} + A_{23} + \ldots)$ the negative sum total of all the transition probabilities from state 2, the equations expressing the constancy of the number in each state take the form $n_1A_{12} + n_2A_{22} + n_3A_{32} + \ldots = 0$ (for state 2). The ratio of two numbers of atoms, *e.g.* $n_3 : n_2$, then can be expressed by the ratio of two minors in the determinant of the coefficients A, and so the ratio of the number of transitions $n_3A_{32} : n_2A_{23}$ can be computed.

The computation becomes somewhat simpler if we introduce the number of atoms in different states in thermodynamic equilibrium n_1°, n_2° . . . If we write the above equation

$$\frac{n_1}{n_1^0} n_1^0 A_{12} + \frac{n_2}{n_2^0} n_2^0 A_{22} + \frac{n_3}{n_3^0} n_3^0 A_{32} + \ldots = 0$$

and put

$$\frac{n_1}{n_1^0} = t_1\ ; \quad \frac{n_2}{n_2^0} = t_2\ ; \quad \ldots\ n_1^0 A_{12} = (12)\ ; \quad n_2^0 A_{22} = (22) = -(21) - (23) - \ldots,$$

* Corresponding to a decrease in velocity of 24 km./hour.

so that t_2 denotes the relative increase or decrease of the atoms in state 2, compared with thermodynamic equilibrium, the equations take the analogous form :

$$(12)t_1+(22)t_2+(32)t_3+\ \ldots\ =0.$$

They may be solved for t_3/t_2 and other ratios in the same elegant way as indicated by Woolley. But now the coefficients (23) and (32) denote the total number of transitions 2–3 and 3–2, which are equal in the case of thermodynamical equilibrium. In other cases the number of upward transitions is multiplied by a factor expressing the weakening of the stimulating radiation (denoted here by the dilution factor W). Strictly speaking, a portion of the downward transitions is also stimulated and has to be multiplied by W. But this fraction is small in all our practical cases, so we will neglect it and consider all the downward transitions as spontaneous.

TABLE I

Number of Transitions n–m

	f	log f all −10	log 3ω	log $e^{-h\nu_{1m}/kT}$	log $(-Ei(-y_n))\times y_n e^{y_n}$	log $(1-e^{-h\nu/kT})^{-1}$	log p_n/p_1	log (nm) all −5
$1S$–$2P$	0·416	9·619	9·553	− 8·531	...	0	0	5·641
$1S$–$3P$	·079	8·898	9·803	−10·110	...	,,	,,	3·591
$1S$–$4P$	·029	8·462	9·849	−10·663	...	,,	,,	2·648
$2S$–$3P$	·425	9·628	8·191	−10·110	...	+·011	,,	2·720
$2P$–$3S$	·014	8·146	,,	,,	...	,,	+·477	1·715
$2P$–$3D$	·694	9·841	,,	,,	...	,,	,,	3·410
$2S$–$4P$	·102	9·009	8·451	−10·663	...	+·003	0	1·800
$2P$–$4S$	·003	7·48	,,	,,	...	,,	+·477	0·75
$2P$–$4D$	·122	9·086	,,	,,	...	,,	,,	2·354
$3S$–$4P$	·484	9·685	7·279	,,	...	+·107	0	1·408
$3P$–$4S$	·032	8·505	,,	,,	...	,,	+·477	0·705
$3P$–$4D$	·619	9·790	,,	,,	...	,,	,,	1·990
$3D$–$4P$	·011	8·041	,,	,,	...	,,	+·699	1·463
$3D$–$4F$	1·016	0·007	,,	,,	...	,,	,,	2·429
$1S$–5	0·436	9·639	9·905	−11·374	−·018	0	0	3·152
$2S$,,	·362	9·559	8·701	,,	−·051	+·001	,,	1·836
$2P$,,	·196	9·292	,,	,,	,,	,,	+·477	2·046
$3S$,,	·293	9·467	7·996	,,	−·107	+·023	0	1·005
$3P$,,	·217	9·336	,,	,,	,,	,,	+·477	1·351
$3D$,,	·100	9·000	,,	,,	,,	,,	+·699	1·237
$4S$,,	·248	9·394	7·497	,,	−·163	+·077	0	0·431
$4P$,,	·214	9·330	,,	,,	,,	,,	+·477	0·844
$4D$,,	·149	9·173	,,	,,	,,	,,	+·699	0·909
$4F$,,	·057	8·756	,,	,,	,,	,,	+·845	0·638

Since Woolley's coefficient is

$$A_{23}=3\omega_{23}f_{23}(e^{h\nu_{23}/kT}-1)^{-1}.W, \quad \text{and} \quad n_2^{\circ}=p_2/p_1.e^{-h\nu_{12}/kT},$$

we have

$$(23)=3\omega_{23}f_{23}.\frac{p_2}{p_1}e^{-h\nu_{13}/kT}(1-e^{-h\nu_{23}/kT})^{-1}.W,$$

and (32) is the same quantity without W. We will make use of the same notation 5 for the ionized state. Then the analogous formulæ for transitions to and from infinity are (χ_1 = ionization energy from the first level, ν_2 = frequency for Balmer series limit):

$$(25) = 3\omega_{25} f_{25} \frac{p_2}{p_1} e^{-\chi_1/kT}(1 - e^{-h\nu_2/kT})^{-1} . W.$$

But a correction, usually small, should be added here, because these transitions are not due to radiations with frequency ν_2 only but are distributed over all frequencies from ν_2 to ∞. This correction is found to be $-Ei(-y_2).y_2/e^{-y_2}$ if $y_2 = \chi_2/kT$.

The radiation falling upon the atoms is radiation of the effective temperature of the Sun (which we take as 6000°), coming from the lower hemisphere only, hence diluted by a factor $W = \frac{1}{2}$, and, moreover, somewhat changed by absorptions. The most important among these changes are the strong absorptions in the lines themselves of frequency ν_{12}, ν_{23} . . . The numerical values of the coefficients, without W, holding for thermodynamic equilibrium, are given in Table I.

2. If we make use of these symbols and values to find the ratio of the number of emissions and absorptions $\alpha = (32)t_3/(23)t_2$ we see that all the terms of numerator and denominator are identical in their numerical part and only different as to the factors W. Some of the terms are entirely identical, others are different as to these factors, and the latter are responsible for the deviation of α from 1. As an example we write here all the terms in the case of the $H\alpha$ component $2P$–$3D$, where only the states $1S$, $2P$, $3D$, 5 are considered, hence (13) = 0. (To save print, the brackets are omitted.)

$$\alpha = \frac{32(51.12.23 + 52.12.23 + 52.15.23 + 53.12.23 + 53.15.23) + 32(53.15.21 + 53.12.25 + 53.15.25)}{\text{Identical terms} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad + 23(51.12.35 + 52.12.35 + 52.15.35)}$$

The numerical parts in logarithms (omitting the factor 23 or 32 everywhere) and the W factors are

12·203	11·097	8·608	10·288	7·799	10·030	8·924	6·435	
W^2	W^2	W^2	W^2	W^2	W	W^2	W^2	(num.)
,,	,,	,,	,,	,,	W^3	W^3	W^3	(denom.)

Hence, neglecting the smallest terms, we have

$$\alpha = \frac{(159{\cdot}6 + 12{\cdot}5 + 1{\cdot}9) + 1{\cdot}07/W}{(159{\cdot}6 + 12{\cdot}5 + 1{\cdot}9) + 1{\cdot}07W} = 1 + \frac{1{\cdot}07}{174}\left(\frac{1}{W} - W\right).$$

This value of $\alpha - 1$ is smaller than Woolley's result, chiefly because of the lower temperature assumed; with his values I find $0{\cdot}015(1/W - W)$, which with $W = 1/3$ would give 0·03, corresponding with his result. Since, however, "colour temperature" denotes only an intensity gradient in a limited part of the spectrum (*cf.* my paper, *M.N.*, 95, 529, 1935), it does not seem right to assume a temperature of 6500° and a dilution factor 1/3. With a dilution factor $W = 1/2$ the result is $\alpha = 1 + 0{\cdot}009$.

For the weakest $H\alpha$ component $2P$–$3S$ we have exactly the same expression, with only the numerical values (23) and (35) different; the result

is $1+\frac{50}{347}\left(\frac{1}{W}-W\right)=1{\cdot}22$. For the third component $2S$–$3P$ the factor (12) = 0, but (13) is present; here the result is found to be only $1+\frac{0{\cdot}82}{353}(1-W)$ $=1+0{\cdot}0012$. Taking account of the relative intensity of each component, it appears that for the combined light $\alpha-1=0{\cdot}011$, only slightly more than it is for the strongest component $2P$–$3D$ alone.

For $H\beta$ we have to substitute 4 for 3 in our formulæ; then the result for the component $2P-4D$ is $1+\frac{0{\cdot}50}{15{\cdot}1}\left(\frac{1}{W}-W\right)=1+0{\cdot}05$. A computation was made to evaluate the influence of the most important intermediary level $3D$ upon the transition 2–4; the inclusion of a 5th term in all the equations made the formulæ of course much more laborious, and the result was only the addition of a term 0·0013 to $\alpha-1$.

We want further on the intensity produced by fluorescence in the central intensity of the first Lyman line $L\alpha$, produced by the transitions 1–2. Here the cycle $1S-2P-5$ gives the simple expression:

$$\alpha=\frac{21(12.51+12.52+15.52)}{12(21.51+21.52+25.51)}$$

$$=\frac{[8.793]W+[7.687]W+[5.198]W}{[8.793]W+[7.687]W+[5.198]W^2}=1+\frac{0{\cdot}16}{670}(1-W)$$

or $\alpha-1=1/8500$. If we include the state $3D$ in our cycle then another term is added amounting to 1/35000.

3. So far for W only the dilution factor 1/2 was used. It includes, however, the total weakening of the relevant radiation, by absorption as well as by dilution of radiation. If we denote by r_{23} the residual intensity in the line with frequency ν_{23}, then for all the upward transitions factors r have to be added to W. We will consider only the chief term in the expression for $\alpha-1$ for the component $2P$–$3D$ of $H\alpha$. This term must then be written

$$\alpha=1+\frac{53.15.21}{51.12.23}\,\frac{(W-W^3)r_{15}}{W^2r_{12}r_{23}}.$$

Now r_{15} is not much different from 1; in the solar spectrum the weakening by the hydrogen absorption bands is imperceptible. The factors r_{12} and r_{23} on the other hand are very small fractions; large factors are thus added to $\alpha-1$ because the direct transitions 1–2 and 2–3 are diminished in number in consequence of the faintness of the exciting radiation. These residual intensities r_{23} . . . are not the surface values which are observed in the spectrum, but the ratio of the total radiation falling upon the atoms in each layer to the black body radiation, hence the values are variable with depth. So we will have to solve the differential equations of the radiation streams to find the true fluorescence effect.

For this purpose it is sufficient to make use of the Schwarzschild approximation of two vertical radiation streams, I and I'. Writing k and s for the absorption and the monochromatic diffusion coefficient, $d\xi$ for $-\rho dh$, the

layer element, $t=k\xi$ for the optical depth and c for $\frac{1}{4}h\nu/kT$, we have in the ordinary case the equations

$$\frac{d}{d\xi}(I+I')=(k+s)(I-I'); \quad \frac{d}{d\xi}(I-I')=k(I+I'-2E); \quad E=E_0(1+ck\xi)$$

or

$$\frac{d^2}{dt^2}(I+I')=\frac{k+s}{k}(I+I'-2E)=m^2(I+I'-2E).$$

By the boundary condition $I'(0)=0$ we have the solution

$$I+I'=E_0(1+ct)-E_0\frac{m-c/m}{1+m}e^{-mt}$$

and the radiation emitted at the surface

$$I_0=\frac{E_0}{m}\frac{c+m}{1+m}, \quad \text{where } 1/m=\sqrt{k/(k+s)}.$$

The expression for $I+I'$ shows the exponential variation with depth. Since in our cases we have to deal with strong absorptions $s>>k$, we may substitute s for $k+s$ and omit c/m, so that $m=\sqrt{s/k}$ and

$$I+I'=E_0(1+ct)-\frac{m}{1+m}E_0e^{-mt}.$$

$I+I'$ is the total radiation falling upon the atoms in the optical depth t, and the residual intensity r occurring in the formulæ is $(I+I')/2E$.

In the case of fluorescence we have to change the second equation, which originally consists of the terms

$$\frac{d}{d\xi}(I-I')=(k+s)(I+I')-2kE-s(I+I')$$

into

$$\frac{d}{d\xi}(I-I')=(k+s)(I+I')-2kE-\alpha s(I+I'),$$

since the third term, the emission from the downward transitions, is α times larger than in the non-fluorescence case. Or, in another form

$$\frac{d}{d\xi}(I-I')=k(I+I'-2E)-(\alpha-1)s(I+I').$$

If now we put $\alpha-1=(\alpha_0-1)/r_{12}r_{23}$ and replace $(I+I')/r_{23}$ by $2E$, this equation may be written

$$\frac{d}{d\xi}(I-I')=k(I+I'-2E)-\frac{\alpha_0-1}{r_{12}}s\,.\,2E=k\left\{I+I'-\left(1+\frac{\alpha_0-1}{r_{12}}\frac{s}{k}\right)2E\right\}.$$

So the change in the equations is restricted to an increase of the $2E$ term.

We will first direct our attention to the factor r_{12}, because Woolley found that the central intensity of this $H\alpha$ line, which would be 0·03 by the dilution of radiation, is raised to 0·23 by the absorption in $L\alpha$. This absorption in $L\alpha$, as Woolley pointed out, takes place only in the uppermost layers of the atmosphere, so that in all moderate depths already $r_{12}=1$. The diffusion

coefficients s for La and Ha have the ratio of their oscillator strengths f_{12} and f_{23}, multiplied by the number of atoms, hence $(0{\cdot}416/0{\cdot}694)\,.\,1/3[8{\cdot}53] = [7{\cdot}83] = 6{\cdot}8 \times 10^7$. If we write $\sqrt{s/k} = q$ for La, then q is of the order 10^4 times the analogous quantity m for Ha, if we are allowed to neglect the variations of k between the wave-lengths of these lines. So we may put for $(I+I')/E$ of La

$$r_{12} = 1 - (1-p)e^{-qt}$$

rapidly increasing to 1 for moderate values of t. The central intensity p in the surface radiation would be $1/q$, about 1/8000, in the non-fluorescence case ; by fluorescence, as we found above, this central intensity is increased by nearly the same amount ; so we take $p = 1/4000$.

Because r_{12} is rapidly changing with t the $2E$ term in the above equation is also rapidly changing. For the case of a variable E the solution for the surface of the ordinary equations may be written

$$I_0 = \frac{1}{1+m}\int_0^\infty E(t)e^{-mt}m\,dt.$$

In our case this becomes

$$I_0 = \frac{1}{1+m}\int_0^\infty E_0\left(1 + \frac{a_0 - 1}{r_{12}}\frac{s}{k}\right)(1+ct)e^{-mt}m\,dt.$$

The correction due to fluorescence is now, substituting the form for r_{12} and neglecting ct,

$$\Delta I_0 = \frac{1}{1+m}\int_0^\infty E_0(a_0-1)\frac{s}{k}\,\frac{e^{-mt}}{1-(1-p)e^{-qt}}m\,dt.$$

Because $m << q$ the integrand is large only for very small values of t. For this integral we have a series development by Poisson

$$\int_0^\infty \frac{e^{-mt}dt}{1-(1-p)e^{-qt}} = \sum_0^\infty \frac{(1-p)^n}{m+nq} = \frac{1}{m} + \frac{(1-p)}{m+q} + \frac{(1-p)^2}{m+2q} + \ldots$$

For very small p a large number of terms of this series must be taken, all of the same order of magnitude, before they begin to decrease. We may evaluate their sum total by neglecting the $m << q$ in the denominator and by substituting an integral for the sum in which n denoted the series of entire numbers. Then

$$\frac{1}{m} + \int_1^\infty \frac{(1-p)^x}{xq}\,dx = \frac{1}{m} + \frac{1}{q}\int_{-ln(1-p)}^\infty e^{-y}\frac{dy}{y} = \frac{1}{m} - \frac{1}{q}Ei(ln(1-p)).$$

For p small we write $ln(1-p) = -p$, and for Ei using the series development we find

$$\frac{1}{m} - \frac{1}{q}(\gamma + lnp - p + \ldots),$$

where γ is Euler's constant. Then the fluorescence term is

$$\Delta I_0 = \frac{E_0}{1+m}(a_0-1)\frac{s}{k}\left(1 + \frac{m}{q}(ln1/p - \gamma + \ldots)\right).$$

For $1-p=0$, or $r_{12}=1$, we have only the first term 1 in the bracket; the other terms are due to the influence of the $L\alpha$ absorption on $H\alpha$. Inserting numerical values $m/q=10^{-4}$, $p=1/4000$, $ln1/p=8{\cdot}5$, we see that they amount to 1/1200. We may conclude that the influence of $L\alpha$ absorption upon $H\alpha$ is entirely negligible. The reason is that it only works in such a thin top layer that no appreciable change in the $H\alpha$ radiation can be brought about.

4. We have now to turn our attention to the first term in ΔI_0, due to the factor r_{23} in the denominator, *i.e.* to the blotting out of the $H\alpha$ light itself. Restoring the factor $1+ct$ the complete value is now

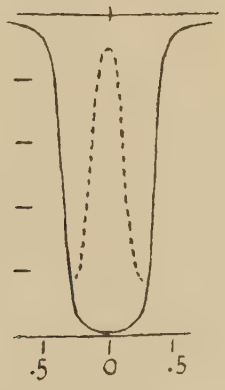
$$I_0=\frac{E_0}{1+m}\left(1+\frac{c}{m}\right)\left(1+(\alpha_0-1)\frac{s}{k}\right),$$

which for $c=1$ may be written

$$I_0=\sqrt{\frac{k}{k+s}}E_0+(\alpha_0-1)\frac{s}{k}\sqrt{\frac{k}{k+s}}E_0.$$

The first term is the ordinary solution, which in the case of $s>>k$ gives a very small fraction, near zero, for $r_{23}=I_0/E_0$. To this intensity now the fluorescence term is added, which for $s>>k$ increases r_{23} by $(\alpha_0-1)\sqrt{s/k}$. So the central intensity can rise to a very high amount.

This fluorescence light does not, however, simply fill up the dark parts of the absorption line. The function s/k for the central parts of a line, the



"Doppler core," shows the figure of a high and narrow Gaussian curve, in the case of H extending to $\Delta\lambda=0{\cdot}4$ A where it disappears in the resonance wings. For $s/k=[4{\cdot}0]e^{-57\Delta\lambda^2}$ (the exponent corresponding to H for 6000°, the coefficient arbitrary) we have for

$\Delta\lambda=$	0	0·1	0·2	0·3	0·4 A
$\sqrt{k/(s+k)}$	0·01	0·013	0·03	0·13	0·70
$0{\cdot}009\sqrt{s/k}$	0·90	0·67	0·29	0·06	0·01

So we see that the profile of the dark absorption line, determined by $\sqrt{k/(s+k)}$, shows a broad bottom of nearly zero intensity. The fluorescence

light, following the function $\sqrt{s/k}$, shows a narrow high peak in the centre. It has, by its origin as well as by its profile, entirely the character of a bright emission line.

Of course we cannot expect to find this emission line in the $H\alpha$ line of the solar spectrum. It is produced in the same layers where the absorption line is formed. Hence it must be broadened by the Stark effect and spread as an average intensity over the broadened absorption line ; the exact value of this intensity must be computed by means of the formulæ for the Stark effect. The narrow reversals actually observed in the solar $H\alpha$ are probably related to temperature inversions in the upper layers of the atmosphere.

Hydrogen, however, was taken here only as an instance, because for the hydrogen atom the transition probabilities are exactly known, so that computation was possible. With other elements the same phenomena must occur, though we cannot compute their amount. So in the centres of their absorption lines narrow emission lines must also occur ; they are much narrower than for hydrogen, because the width of the Doppler core of the s function decreases as the inverse square root of the atomic weight, whereas for strong absorption lines the total width is determined by the broad resonance wings. Since in such strong lines s/k in the centre has a high value of the order of 10^5 or 10^6, very small values of $\alpha_0 - 1$ are sufficient to produce perceptible central emission lines. If we consider that the width of the central core of a metal absorption line is $< 0{\cdot}1$ *A* and usually cannot be distinguished, it is clear that the detection of the still narrower emission line is still more difficult.

But cannot they be seen in the solar spectrum? Dr. Mulders, in this connection, drew my attention to the fact that in Rowland's Preliminary Table of Solar Spectrum Wave-lengths several strong lines (*e.g.* 3922 *Fe*, 4216 Sr^+, 4275 *Cr*, 4225 *Ca*) have a *d* attached to their intensity number, indicating duplicity, for which, however, no physical reason can be found. It is well known that the high quality of Rowland's solar spectrum plates has never been surpassed or even reached afterwards, and that they show faint lines and details not seen on other plates. So it seems probable that he has seen the narrow central emission lines in some of his absorption lines, and interpreted them as a duplicity of the line. When they are so difficult objects on his plates it is easily understood that on ordinary negatives they are invisible. Here their light, by the lack of resolving power of instruments and plates, is diffused into a general moderate brightening of the dark central parts of the absorption lines.

LIMB DARKENING.

A. Pannekoek.

In my paper on "Theoretical Colour Temperatures" * I pointed out how the variation of the absorption coefficients of a stellar atmosphere with wave-length and temperature determines a deviation of the so-called colour temperatures from the real (effective) temperatures. It is easily seen that it has also an important bearing upon the coefficient of limb darkening.

The intensity emitted at the surface of the atmosphere in any direction, making an angle θ with the external radius, is determined by

$$I_0 = \int_0^\infty E(\tau) e^{-\tau \sec\theta} \sec\theta \, d\tau,$$

where τ is the optical depth, and the black body radiation at this depth τ is given by

$$E(\tau) = E_0(1 + \tfrac{3}{2} c\tau \bar{k}/k) = E_0(1 + C\tau).$$

The result of the integration is

$$I_0 = E_0(1 + \tfrac{3}{2} c\bar{k}/k \cos\theta) = E_0(1 + C\cos\theta).$$

Then the coefficient of limb darkening

$$u \equiv \frac{I(0) - I(90)}{I(0)} = \frac{C}{1 + C}$$

is seen to depend in a very simple way upon this $C \equiv \tfrac{3}{2} c\bar{k}/k$.

For the total radiation, if C is taken simply $3/2$ we have $u = 0{\cdot}60$, as was first deduced by Milne.† If we take account of c only, which expresses the bluer colour of the radiation of the deeper layers, we find u increasing from $0{\cdot}60$ for λ 6000 A. to $0{\cdot}69$ for λ 4000 A., hence there is a reddening of the limb. If now we take account of the factors $\bar{k}/k$ the limb darkening is found to vary with temperature too.

We take the values of C from Table 26 in Publ. No. 4 of the Amsterdam Astronomical Institute (where C depends on gravitation, *i.e.* for temperatures $9500 - 5000°$, the value for the solar gravity $\log g = 4{\cdot}4$ is taken). Then we find the results given in the following table.

* *M.N.*, **95**, 529, 1935.
† *M.N.*, **81**, 371, 1921.

[TABLE

T	C			u		
	6000 A.	5000 A.	4000 A.	6000 A.	5000 A.	4000 A.
25200°	0·03	0·06	0·13	0·03	0·06	0·12
16800°	0·09	0·17	0·40	·08	·15	·29
12600°	0·30	0·60	1·38	·23	·38	·58
10080°	0·69	1·38	3·3	·42	·58	·77
8400°	1·00	2·00	4·8	·50	·67	·83
7200°	1·44	2·35	4·0	·59	·70	·80
6300°	2·05	2·45	2·25	·67	·71	·69
5600°	2·35	2·25	1·55	·70	·69	·61
5040°	2·35	2·00	1·20	·70	·67	·55
4200°	2·05	1·41	0·62	·67	·60	·38

The variations of limb darkening with temperature and wave-length, appearing in these values, can be expressed in the following qualitative form. For B-type stars the limb darkening is small. For A-type stars it is very large in the blue, strongly decreasing to the larger wave-lengths. For stars of advanced type, G–K, the limb darkening is smaller for blue than for yellow rays, so that the darkened limb of these stars must appear more bluish than the centre. For the Sun we may deduce the limb darkening from the values of the limb-intensity (for $\sin\theta = 0{\cdot}95$, $\cos\theta = 0{\cdot}312$) given by Milne * after a table computed by Lindblad.† We have for

λ	3737	4265	5062	5955	6702
limb-intensity	0·432	0·445	0·529	0·595	0·640 (centre = 1)
u	0·83	0·81	0·68	0·59	0·52

Hence for 6000 A., 5000 A., 4000 A. the observed u is nearly 0·59, 0·69, 0·82. So here we have the same discrepancy as was noted for the colour temperature ; solar phenomena correspond to those computed theoretically for a temperature of over 7000°. This indicates that the computed absorption coefficients need still some correction.

These results may have some importance for the eclipsing variables, the only stars where we can find observational evidence about limb darkening. It will be interesting to test the theoretical values, especially the strong dependence on wave-length, by accurate photoelectric measures of the appropriate eclipsing variables in their minima.

* *Thermodynamics of the Stars*, p. 149 ; *Handbuch der Astrophysik*, III, 1.

† *Nova Acta Upsala*, **6**, i, p. 17, 1923.

A NOTE ON AN ISOTROPIC SOLUTION IN RELATIVITY.

V. V. Narliker and D. N. Moghe.

1. *Condition of Isotropy*

For a line-element of the form

$$ds^2 = -e^{\mu}(dr^2 + r^2 d\theta^2 + r^2 \sin^2\theta d\phi^2) + e^{\nu} dt^2 \tag{1}$$

with

$$\mu \equiv \mu(r, t) \quad \text{and} \quad \nu \equiv \nu(r, t),$$

and for the energy-tensor *

$$T_{\mu}^{\nu} = (\rho_{00} + p) g_{\mu\sigma} v^{\sigma} v^{\nu} - p\delta_{\mu}^{\nu}, \tag{2}$$

the condition of isotropy has generally been assumed to be

$$T_1^1 = T_2^2 = T_3^3. \tag{3}$$

In a recent paper Walker † has criticised this assumption. He points out that the physical condition of isotropy is implied in (2) and that the components of the energy-tensor, calculated for a line-element of the form (1), satisfy identically the relation

$$e^{\nu}[T_1^4]^2 + e^{\mu}[T_2^2 - T_4^4][T_2^2 - T_1^1] = 0. \tag{4}$$

This is the condition of isotropy and its form remains invariant for all line-elements of the form (1), while, as Walker has shown, (3) is not such an invariant condition.

The condition (3) implies that $T_1^4 = 0$, as is obvious from (4). It means

$$e^{-\nu}(\dot{\mu}' - \dot{\mu}\nu'/2) = 0, \tag{5}$$

where a dot denotes a differentiation with regard to t and a dash denotes a differentiation with regard to r. Solving (5) one obtains

$$e^{\mu} = \phi(r) e^{\int \psi(t) e^{\nu/2} dt}, \tag{6}$$

$\phi(r)$ and $\psi(t)$ being arbitrary functions. Thus (3) implies the restriction (6) upon the forms of μ and ν.

As no solution of Einstein's equations seems to have been given which satisfies the condition of isotropy (4) and which, therefore, does not imply a restriction like (6) upon μ and ν, we proceed to consider here one such solution.

* R. C. Tolman, *Relativity, Thermodynamics, and Cosmology*, p. 217, 1934.

† A. G. Walker, *Q.J. Maths.* (Oxford Series), **6**, 22, 89.

2. *Integration of the Condition of Isotropy*

When the expressions for the components of the energy-tensor are substituted in (4) a differential equation is obtained which has not yet been solved. A solution may be obtained assuming

$$\mu = \mu(t) \quad \text{and} \quad \nu = \nu(r). \tag{7}$$

The condition of isotropy now gives the differential equation

$$4e^{-\nu}(\dot{\mu}\nu')^2 - [2\nu'' + \nu'^2 - 2\nu'/r][4e^{-\nu}\ddot{\mu} - e^{-\mu}(2\nu'' + \nu'^2 + 2\nu'/r)] = 0. \tag{8}$$

It gives the solution

$$e^{\nu} = r^2, \qquad e^{\mu} = A + Bt + \tfrac{1}{2}t^2, \tag{9}$$

A and B being arbitrary constants. It may be noted that μ and ν as given in (9) are not subject to the restriction (6). The flow of matter is given by

$$T_1^4 = \frac{1}{8\pi r^3} \cdot \frac{B+t}{A+Bt+\frac{1}{2}t^2}. \tag{10}$$

There is a singularity at the origin which may be interpreted as a high concentration of matter there. The density is, if $A = B = 0$,

$$T_4^4 = (3/r^2 - \lambda t^2)/8\pi t^2. \tag{11}$$

So the density vanishes when

$$r^2 = 3/\lambda t^2. \tag{12}$$

In Milne's theory * $\lambda t^2 = 3/e^2$. Hence for large values of t, or if the arbitrary constants A and B are chosen to be zero, Milne's relation gives the fixed boundary value of r where the proper density vanishes.

3. *Trajectories*

It may be of some interest to investigate whether anything like the law of recession for the nebulæ holds good for particles in the field of the line-element (1). The geodesics are given by

$$\frac{d^2r}{ds^2} + \frac{B+t}{A+Bt+\frac{1}{2}t^2}\frac{dr}{ds}\cdot\frac{dt}{ds} + \frac{r}{A+Bt+\frac{1}{2}t^2}\left(\frac{dt}{ds}\right)^2 = 0. \tag{13}$$

$$\frac{d^2t}{ds^2} + \frac{B+t}{2r^2}\left(\frac{dr}{ds}\right)^2 + \frac{2}{r}\frac{dr}{ds}\cdot\frac{dt}{ds} = 0. \tag{14}$$

It follows from the last two equations that

$$\ddot{r} - \dot{r}\left[\frac{(B+t)\dot{r}^2}{2r^2} + \frac{2\dot{r}}{r}\right] + \frac{(B+t)\dot{r}+r}{A+Bt+\frac{1}{2}t^2} = 0. \tag{15}$$

This has a solution of the form

$$\dot{r}/r = c/t, \tag{16}$$

* E. A. Milne, *Relativity, Gravitation and World-Structure*, p. 293, 1935.

provided A and B are assumed to be zero, in which case

$$c = \pm\sqrt{2}, \qquad -2. \tag{17}$$

$c = 1$ corresponds to the law of recession in Milne's theory. It is interesting to note that while $c = \sqrt{2}$ permits a recession as in Milne's theory, the values $-\sqrt{2}$ and -2 of c indicate that a motion of approach similar to that of recession is also possible in the field of (1).

[NOTE (added later): In a letter to *Nature*, now in the press, Narlikar and K. V. Sastry point out that the line-element (1) with $A = B = 0$ gives spiral orbits with motion according to the equations

$$\dot{r}/r = \lambda/t, \qquad \dot{\phi} = \sqrt{(2 - \lambda^2)}/t,$$

$\lambda > 0$ being a constant of integration.—V. V. N. and D. N. M.]

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India.

PREFERENTIAL MOTION AND MEAN PARALLAXES.

A. Fletcher, M.A., Ph.D., and A. Mulligan, B.Sc.

1. The present communication completes a previous one,* which may be consulted and will not be described here. It need only be said that exact calculation was at one stage † abandoned in favour of a crude process of approximation, although it was noted that a reduction in terms of elliptic integrals was possible. This reduction will now be given, and some previous numerical approximations will be refined by exact calculation.

2. It is required † to evaluate the integral

$$f'(0) = \frac{1}{\pi}\int_0^{\pi}\left\{1 + \left(\frac{c^2}{a^2} - 1\right)\sin^2\gamma\,\sin^2\psi\right\}^{\frac{1}{2}} d\chi, \tag{1}$$

where

$$\cos\alpha\cos\gamma = \sin\gamma\cot\chi - \sin\alpha\cot\psi. \tag{2}$$

3. Equation (2) gives $\cot\chi = l\cot\psi + m$, where

$$l = \sin\alpha\,\mathrm{cosec}\,\gamma, \qquad m = \cos\alpha\cot\gamma. \tag{3}$$

Substituting in (1), and performing some reduction, we have

$$f'(0) = \frac{1}{\pi}\int_0^{\pi}\frac{p\cos^4\psi + q\cos^2\psi + r}{f\cos^4\psi + g\cos^2\psi + h}\,\frac{l\,d\psi}{\sqrt{(1 + \kappa^2\sin^2\psi)}},$$

where

$$\kappa^2 = (c^2/a^2 - 1)\sin^2\gamma, \tag{4}$$

* Fletcher, *M.N.*, **92**, 780, 1932. † *Loc. cit.*, p. 784.

$$\left.\begin{aligned} p &= \kappa^2(1-l^2+m^2), \\ q &= (1+\kappa^2)l^2-(1+2\kappa^2)(1+m^2), \\ r &= (1+\kappa^2)(1+m^2), \end{aligned}\right\} \tag{5}$$

$$\left.\begin{aligned} f &= 1-2l^2+2m^2+l^4+2l^2m^2+m^4, \\ g &= 2(l^2-2m^2-1-l^2m^2-m^4), \\ h &= (1+m^2)^2. \end{aligned}\right\} \tag{6}$$

If we write

$$k^2=\kappa^2/(1+\kappa^2), \qquad k'=\sqrt{(1-k^2)}, \qquad \phi=\tfrac{1}{2}\pi-\psi, \tag{7}$$

we thus have

$$f'(0)=\frac{2lk'}{\pi}\int_0^{\frac{1}{2}\pi}\frac{p\sin^4\phi+q\sin^2\phi+r}{f\sin^4\phi+g\sin^2\phi+h}\,\frac{d\phi}{\sqrt{(1-k^2\sin^2\phi)}}. \tag{8}$$

4. It may be verified from equations (6) that the expression

$$f\sin^4\phi+g\sin^2\phi+h$$

has complex factors, the discriminant, g^2-4fh, being equal to $-16l^4m^2$. Let us then write

$$\frac{p\sin^4\phi+q\sin^2\phi+r}{f\sin^4\phi+g\sin^2\phi+h}\equiv A+\frac{B}{1+n\sin^2\phi}+\frac{B^*}{1+n^*\sin^2\phi},$$

where B, B^* and n, n^* are complex conjugates. Putting

$$B=B_1+iB_2, \qquad B^*=B_1-iB_2, \tag{9}$$

$$n=n_1+in_2, \qquad n^*=n_1-in_2, \tag{10}$$

we find that

$$A=\frac{p}{f}, \qquad B_1=\frac{fr-hp}{2fh}, \qquad B_2=\frac{2fhq-ghp-fgr}{2fh\sqrt{(4fh-g^2)}}, \tag{11}$$

$$n_1=\frac{g}{2h}, \qquad n_2=\frac{\sqrt{(4fh-g^2)}}{2h}. \tag{12}$$

Thus the problem is reduced to the evaluation of

$$f'(0)=\frac{2lk'}{\pi}\int_0^{\frac{1}{2}\pi}\left(A+\frac{B}{1+n\sin^2\phi}+\frac{B^*}{1+n^*\sin^2\phi}\right)\frac{d\phi}{\Delta\phi}, \tag{13}$$

where $\Delta\phi=\sqrt{(1-k^2\sin^2\phi)}$. All square roots mentioned above are taken as positive.

5. The complete first integral, $\int_0^{\pi/2}d\phi/\Delta\phi$, usually denoted by K or $F_1(k)$, has been tabulated. Consider then the evaluation of the complex conjugates $\Pi_1(n)$ and $\Pi_1(n^*)$, where, in Legendre's notation for the complete third integral,

$$\Pi_1(n)=\int_0^{\frac{1}{2}\pi}\frac{d\phi}{(1+n\sin^2\phi)\Delta\phi}, \qquad \Pi_1(n^*)=\int_0^{\frac{1}{2}\pi}\frac{d\phi}{(1+n^*\sin^2\phi)\Delta\phi}. \tag{14}$$

These integrals can be expressed in terms of incomplete first and second integrals. Namely, if

$$n=-k^2\sin^2\theta, \qquad n^*=-k^2\sin^2\theta^*, \tag{15}$$

we have * $$\left.\begin{aligned}\Pi_1(n) &= F_1 + \tan\theta(\Delta\theta)^{-1}\{F_1E(\theta) - E_1F(\theta)\},\\ \Pi_1(n^*) &= F_1 + \tan\theta^*(\Delta\theta^*)^{-1}\{F_1E(\theta^*) - E_1F(\theta^*)\},\end{aligned}\right\} \tag{16}$$

where

$$F(\theta) = \int_0^\theta d\phi/\Delta\phi, \qquad E(\theta) = \int_0^\theta \Delta\phi\,.\,d\phi, \qquad F_1 = F(\tfrac{1}{2}\pi), \qquad E_1 = E(\tfrac{1}{2}\pi). \tag{17}$$

A few words must be said about various ambiguities. From (15) we have $\sin\theta = S$, where S is a definite square root, chosen once for all, of $-n/k^2$. We also have

$$\cos\theta = C = \sqrt{(1-S^2)}, \qquad \Delta\theta = D = \sqrt{(1-k^2S^2)},$$

where the roots are defined uniquely as the values reached by $\sqrt{(1-z^2)}$ and $\sqrt{(1-k^2z^2)}$ respectively, both starting from $+1$ when $z=0$, as the point z moves in a straight line from 0 to S on an Argand diagram. A similar understanding applies to the integrals $F(\theta)$ and $E(\theta)$. Namely, we have

$$F(\theta) = \int_0^S \frac{dz}{\sqrt{\{(1-z^2)(1-k^2z^2)\}}}, \qquad E(\theta) = \int_0^S \sqrt{\left(\frac{1-k^2z^2}{1-z^2}\right)}dz, \tag{18}$$

where the integrands equal $+1$ when $z=0$, and z moves straight from 0 to S. It is evident that the values of C^*, D^*, $F(\theta^*)$ and $E(\theta^*)$ similarly defined, with z moving straight from 0 to S^*, the conjugate of S, are the conjugates of C, D, $F(\theta)$ and $E(\theta)$ respectively.

With the above interpretations, the theorem embodied in (15) and (16) remains valid for complex n. It is in fact a translation into Legendre's notation, putting $\theta = \operatorname{am} a$, of the Jacobian result $\Pi(K, a) = KZ(a)$, which naturally is valid for complex a.

6. It remains to evaluate $F(\theta)$, $E(\theta)$ and their conjugates. It is convenient to determine twice the real and imaginary parts separately, from the addition-theorems giving

$$F(\theta)+F(\theta^*), \qquad F(\theta)-F(\theta^*), \qquad E(\theta)+E(\theta^*), \qquad E(\theta)-E(\theta^*).$$

7. We have the well-known theorem that

$$F(\theta)+F(\theta^*) = F(\mu, k), \tag{19}$$

where $$\sin\mu = \frac{SC^*D^* + S^*CD}{1-k^2S^2S^{*2}}, \qquad \cos\mu = \frac{CC^* - SS^*DD^*}{1-k^2S^2S^{*2}}. \tag{20}$$

But $F(\theta)$, defined as in section 5, is the principal value of $\operatorname{sn}^{-1}S$, which is known, from the details of the transformation $z = \operatorname{sn} u$, to have its real part between $\pm K$. Thus $F(\mu)$ lies between $\pm 2K$, and μ lies between $\pm\pi$. Hence μ is uniquely determined by equations (20).

8. We have also that

$$F(\theta) - F(\theta^*) = F(\mu', k), \tag{21}$$

where $$\sin\mu' = \frac{SC^*D^* - S^*CD}{1-k^2S^2S^{*2}}, \qquad \cos\mu' = \frac{CC^* + SS^*DD^*}{1-k^2S^2S^{*2}}. \tag{22}$$

* As in Cayley, *Elliptic Functions*, 1895, pp. 140–141, except that n is now complex.

Since $\sin \mu'$ is imaginary, the equivalent of Jacobi's imaginary transformation must be used. Let

$$\sin \mu' = i \tan \nu, \qquad \cos \mu' = \sec \nu, \qquad -\pi < \nu < \pi ; \tag{23}$$

then

$$F(\theta) - F(\theta^*) = iF(\nu, k'). \tag{24}$$

It will be noticed that $\sec \nu \gtrless 0$, and thus $|\nu| \lesssim \frac{1}{2}\pi$, according as $|S| \lesssim 1/\sqrt{k}$.

Since $F(\frac{1}{2}j\pi, k') = j'K'$, where the integral parts of real j and j' are the same, the above formulation accords with the facts that (i) the principal value of $\mathrm{sn}^{-1} S$ has its imaginary part between $\pm iK'$, (ii) this imaginary part lies inside or outside the limits $\pm \frac{1}{2}iK'$ according as $|S| \lesssim 1/\sqrt{k}$.*

9. In the case of $E(\theta)$ we have †

$$E(\theta) + E(\theta^*) = E(\mu, k) + k^2 SS^* \sin \mu, \tag{25}$$

where μ again satisfies (20) and lies between $\pm \pi$.

10. We have also that

$$E(\theta) - E(\theta^*) = E(\mu', k) - k^2 SS^* \sin \mu', \tag{26}$$

where $\sin \mu'$, $\cos \mu'$ have the same values as in (22). Again introducing ν by (23), we have ‡

$$E(\mu', k) = iF(\nu, k') - iE(\nu, k') + i \tan \nu \sqrt{(1 - k'^2 \sin^2 \nu)}, \tag{27}$$

where the square root is positive.

11. In spite of the occurrence of complex quantities, it has been convenient to use Legendre's notation for the integrals, but this procedure is not without its risks, and it has been found almost essential to bear the standard Jacobian notation continually in mind. In this paper, however, our primary aim has been the *statement* of formulæ which can be applied to numerical computation with the help of a minimum amount of equipment as regards both knowledge and tables of elliptic functions.

It should perhaps be added that $E(\theta)$ may be computed by a different process. If $F(\theta) = u_1 + iu_2$, then

$$E(\theta) = E\{u_1 + iu_2\} = E\{u_1\} + E\{iu_2\} - k^2 \,\mathrm{sn}\, u_1 \,\mathrm{sn}\, iu_2 \,\mathrm{sn}(u_1 + iu_2),$$

where Jacobi's functional E is associated with curled brackets. With the help of the imaginary transformation this expression may be evaluated without difficulty. The numerical value of $E(\theta)$ given in section 12 has in fact been checked by this process, which appears to offer no advantage over that outlined above. A similar remark applies to the use of the theorem on the addition of parameters in Jacobi's form of the third integral.

* See A. C. Dixon, *Elliptic Functions*, 1894, Appendix A. This also contains formulæ which provide an alternative means of computing the real and imaginary parts of $F(\theta)$, and have been used to check the numerical values given below in section 12.

† Cayley, *Elliptic Functions*, 1895, p. 7.

‡ *E.g.* by substituting $u = F(\nu, k')$ in the formula for the imaginary transformation of Jacobi's $E(u)$. Whittaker and Watson, *Modern Analysis*, 1920, § 22·734.

12. Some details of the numerical calculation in the case

$$\alpha = 35^\circ, \qquad \gamma = 45^\circ, \qquad c/a = 1{\cdot}6$$

will now be given. The values of the elliptic integrals are taken from Dale's *Five-Figure Tables*.

$\kappa^2 = 0{\cdot}7800$ $\quad p = \ 0{\cdot}7902$ $\quad f = \ 2{\cdot}7923$
$l = 0{\cdot}8112$ $\quad q = -3{\cdot}1066$ $\quad g = -5{\cdot}1516$
$m = 0{\cdot}8192$ $\quad r = \ 2{\cdot}9744$ $\quad h = \ 2{\cdot}7923$

$k^2 = 0{\cdot}4382 = \sin^2 41^\circ{\cdot}45$ $\quad B = \ 0{\cdot}3911 + 0{\cdot}1698i$
$A = 0{\cdot}2830$ $\quad n = -0{\cdot}9225 + 0{\cdot}3861i$

$S = \sin\theta = 1{\cdot}4811 - 0{\cdot}2974i$ $\quad D = \Delta\theta = 0{\cdot}4854 + 0{\cdot}3976i$
$C = \cos\theta = 0{\cdot}3925 + 1{\cdot}1222i$ $\quad S/CD = -1{\cdot}0549 - 1{\cdot}7285i$

$\mu = 180^\circ - 66^\circ{\cdot}33$ $\quad E(\mu) = 1{\cdot}6973$
$\nu = 56^\circ{\cdot}32 - 180^\circ$ $\quad E(\theta) + E(\theta^*) = 2{\cdot}6131$
$F(\theta) + F(\theta^*) = \ 2{\cdot}3451$ $\quad E(\mu') = 0{\cdot}1601i$
$F(\theta) - F(\theta^*) = -2{\cdot}7461i$ $\quad E(\theta) - E(\theta^*) = -1{\cdot}3405i$
$F(\theta) = 1{\cdot}1726 - 1{\cdot}3731i$ $\quad E(\theta) = 1{\cdot}3066 - 0{\cdot}6703i$

$\Pi_1(n) = 2{\cdot}2121 - 2{\cdot}0016i$ $\quad f'(0) = 1{\cdot}1306$

13. A similar calculation gives $f'(0) = 1{\cdot}2344$ when $c/a = 2{\cdot}0$. We thus have the following values :—

TABLE I

Values of $f'(0)$ *for* $\alpha = 35^\circ$, $\gamma = 45^\circ$

c/a	(1)	(2)	(3)
1·6	1·14	1·131	1·1306
2·0	1·25	1·234	1·2344

The values (1) were found previously,* by an approximation known to yield too large a result. The values (2) were obtained (for $c/a = 2{\cdot}0$ by numerical quadrature, and for $c/a = 1{\cdot}6$ by consequent empirical correction, on lines which will not be described here) in a recent dissertation.† The values (3) are those now found by an exact process. It appears that the values (2) are reliable. The values of $e'(0)$ and $\Delta M(0)$ over a wider range in c/a are therefore reproduced here from the second source.† They supersede the values previously published.*

TABLE II

$\alpha = 35^\circ$, $\gamma = 45^\circ$

c/a	1·0	1·2	1·4	1·6	1·8	2·0	2·2
$e(0)$	0·0	4·0	8·3	13·1	18·1	23·4	28·9
$\Delta M(0)$	$+0^m{\cdot}00$	$+0^m{\cdot}13$	$+0^m{\cdot}24$	$+0^m{\cdot}33$	$+0^m{\cdot}41$	$+0^m{\cdot}48$	$+0^m{\cdot}55$

Department of Applied Mathematics,
University of Liverpool :
1935 *Sept.* 20.

* *M.N.*, **92**, 780, Table IV, 1932.
† Fletcher, *Dissertation* (Cambridge, 1934).

A DETERMINATION OF THE PROFILE OF THE CALCIUM LINE λ 4227 IN THE SOLAR SPECTRUM, USING A PRISM SPECTROGRAPH AND MONOCHROMATOR.

R. O. Redman, M.A., Ph.D.

Summary.—The profile of λ 4227 in light taken from the centre of the Sun's disc has been determined with a prism spectrograph of high dispersion, fed through a monochromator. The measured central intensity is 4·8 per cent. of the adjacent continuous spectrum; it is 7·9 per cent. when the same instrument is used without the monochromator, the difference being due to scattered light within the spectrograph. The instrumental profile given by the spectrograph has been measured. The correction for finite resolving power derived from this profile reduces the central intensity of λ 4227 to 2 per cent.

Introduction.—The first application of a monochromator to the determination of line profiles was made by Dunham at Mt. Wilson, but very little has been published with regard to the details of instrumental arrangements or to the results obtained.* Recently Thackeray † gave measurements of central intensities of a few Fraunhofer lines, using a Rowland concave grating fed through a monochromator which was devised for this purpose by the writer. It appeared that a great deal of false light, scattered or diffracted into the region near the centre of the line, could by this means be eliminated and the accuracy of measurement substantially improved. Since the completion of that work a similar monochromator has been used with the McClean spectrograph at the Solar Physics Observatory, Cambridge, and the profile of the neutral calcium line, λ 4227, has been determined, with special attention to the central parts of the line.

Instrument.—The McClean spectrograph was originally a grating instrument, Littrow mounting, with a lens of aperture 10 cm. and focal length 427 cm. The grating has been replaced by three 60° and one 30° prisms, of 5·5 cm. aperture, giving a spectrum of scale 0·64 A./mm. at λ 4227. Between slit and plate the light passes effectively 23 optical surfaces, so that we may expect plenty of scattered light in the instrument. The lens was not tilted for the work about to be described, as may be done in order to get rid of the light from a certain number of reflections, although there was the customary black strip across its centre. With the monochromator in use the effect of the reflections becomes negligible and it was desired to find out how much would be the effect of scattered light in a rather bad case. Apart from this, the definition appeared better with the lens not tilted, which provided another good reason for leaving it with its axis midway between slit and plate centre. To obtain good definition

* *Mt. Wilson Annual Report*, 1930–31, p. 194.

† *M.N.*, **95**, 293, 1935.

regularly it was found essential to control the temperature of the prisms with a thermostat. This has been done but the prism box only is controlled, the main body of the instrument is unaffected by the thermostat, although it is wrapped in insulating material. It is presumably for this reason that shifts occur in the spectrum lines during any long exposure, unless the temperature in the surrounding room happens to be constant. These shifts occur while the thermostat is working and the definition for brief exposures is at its best. Exposures on the solar spectrum, being always short, are unaffected by these shifts, although they gave rise to some trouble in another phase of the work, as will be described later.

The monochromator was used in a slightly different form from that described in *M.N.*, **95**, 290, 1935. Glass prisms were used instead of quartz, and each diagonal mirror M_1 or M_2 (see figure, p. 291, *loc. cit.*) was placed between its respective lens, L_1 or L_2, and the prisms. This modification makes appreciably easier the task of collimating the various optical parts and is due to Mr. W. Moss, who gave a great deal of help in setting up the instrument. Mr. Moss has also pointed out that the monochromator would be very much easier to adjust in wave-length if field lenses were used in the beam near the second slit. However, since the observations described here were all at one wave-length this improvement was not tried.

The solar image on the first slit of the monochromator was formed by a 10-cm. lens of 6·4 m. focal length and hence was about 53 mm. in diameter. A length of slit about 9 mm. was used for the earlier plates ; later this was cut down to about 4 mm. Observations were made only at the centre of the disc. Most of the plates, both with and without monochromator, were taken on 1935 May 3, when the disc showed an average amount of activity and there were no special disturbances in the region from which light was taken. The monochromator slits were varied so that the length of spectrum photographed varied from about 7 A. to 24 A., according to whether measurements were to be made near the line centre or in the line wings. The slit width of the main spectrograph was 0·05 mm.

Photographic Procedure.—Backed Ilford Empress plates were used. Twenty-six exposures with monochromator were measured (exposure times 5 seconds to 2 minutes) and 12 without monochromator (exposure times $\frac{1}{4}$ to 5 seconds).

Each plate was cut in two, half being exposed to the solar spectrum, the other half to a continuous spectrum in a calibrating spectrograph, the two exposures being almost simultaneous. The two halves were developed together in a concentrated M-Q developer, being brushed throughout. There appears to be no mode of development which renders quite impossible the occurrence of any Eberhard effect, but the procedure mentioned is as satisfactory as any other in this respect, according to tests made at the Solar Physics Observatory. On only one plate was any suggestion of Eberhard effect noticed.

The calibration spectrograph is provided with an optical wedge of neutral-tint glass, placed over its slit. The wedge had already been calibrated but it was felt desirable to check the calibration. This was done

in the manner described in the next section. Normally this procedure would not have been described but it is included on account of the fact that the results were somewhat unusual.

The difference of exposure times between solar spectrum and calibration spectrum (exposure time normally one minute) may safely be neglected, since the variation of the characteristic curve of a photographic plate with exposure time is extremely small.

Wedge Calibration.—The wedge used was of the normal type, in which the thickness of the absorbing layer varies linearly with height measured along the wedge itself. It may therefore be assumed that the transmission of light obeys the law

$$\log I_1/I_2 = k\lambda(x_1 - x_2),$$

where I_1 and I_2 are transmitted intensities at heights x_1 and x_2 respectively and $k\lambda$ is a constant for a given wave-length. In other words, if $\log I$ is plotted against x the result is a straight line, the slope of the line giving the "wedge constant" $k\lambda$. It is possible to use heights on the wedge image formed by the spectrograph and to define $k\lambda$ so that the wedge equation refers to these image heights, instead of to heights on the wedge itself. The purpose of this section is to demonstrate that considerable error may be caused by an unverified assumption that the graph of $\log I$ plotted against height on a wedge image is a straight line.

The wedge was calibrated in position on the calibrating spectrograph. The required exposures of known intensity ratios were made by two independent methods, both using a third spectrograph, not the calibrating or Littrow instruments. The method on which chief reliance was placed used variable slit widths. The procedure is well known and need not be described in detail. The slit widths were measured carefully before and after the exposures, mean values being used for reducing the plates. Precaution was taken that the lamp was thoroughly warmed up before the first exposure was made, and the order of exposures was such as to minimize the effect of variations of the lamp during the exposures or variations of the photographic latent image between exposure and development. Fifteen plates, each including two wedge exposures and one series of calibrating exposures, were measured, and one rejected owing to inadequate comparison spectrum.

The second method relied on diaphragms, used in an unfocussed beam outside the spectrograph. About 80 A. of a continuous spectrum, centred on λ 4227, were isolated by a slit in the focal plane of the auxiliary spectrograph, whose camera works at f 10. (It was assumed that the plate characteristics for this light are the same as for strictly monochromatic light of wave-length λ 4227.) The light fell on a smooth magnesia block, placed diagonally some 40 cm. behind the slit just mentioned. In a direction at right angles to the original beam and 38 cm. from the block was a ground-glass screen, behind which could be placed one of 5 interchangeable diaphragms, each with 17 equal holes drilled in a regular geometrical pattern. The orientation of the pattern was kept the same throughout

all exposures. The total aperture areas in the diaphragms were proportional to 100·00, 60·37, 39·25, 21·85 and 11·92 respectively. The diameter of the diaphragms was about 4 cm. The plate was placed about 15 cm. from the diaphragm used, with a screen to limit the area of plate illuminated. Exposures were made with the usual precautions to maintain uniformity of light flux through the spectrograph.

Backed Ilford Special Rapid plates, brush developed in M-Q, were used throughout the wedge calibration.

The two methods gave very satisfactory agreement, as may be seen in fig. 1. The important feature of the results is that the graph of log I against height on the wedge image is *not* a straight line.* The less luminous end of the wedge image has greater intensity than expected. The simplest explanation is that there is a certain amount of scattered light in the standardizing spectrograph. Indeed, making the assumption that there is uniformly scattered light over the plate of intensity rather less than 1 per cent. of that transmitted by the thin end of the wedge (*i.e.* in the densest part of the photographic image), very nearly all the curvature observed in the graph can be accounted for. The calibrating spectrograph, which was made up some years ago from odd optical parts, has 10 air-glass and 2 glass-glass surfaces between slit and plate. This is about half the number in the Littrow spectrograph, where scattered light was found to be 3 per cent. of the continuous spectrum, so that one might here expect a scatter of the order suggested by the wedge calibration. It was noticed that the wedge "constant" from the earlier calibration of the wedge agrees with the top part of the curve given here, which is as it should be if lightly exposed wedge images were being used.

It may be pointed out that no appreciable error can arise from scattered light if present in the auxiliary spectrograph used for the wedge calibration. The only effect of such scatter is to add to the light reaching the plate a small amount of light of other wave-lengths. The method of varying the light intensity is such that the scattered light is also changed in the same ratios. In other words, one works with a beam slightly less monochromatic than expected, but since the change of plate characteristics with wave-length is slow, the net effect on the calibration will be negligible.

For the determination of the profile of λ 4227, intensities in the wedge image were taken from the graph shown. It is estimated that the error in log I is unlikely to exceed 0·005 except beyond $h = 6{\cdot}5$. Between 6·5 and 7·5 it may be in error by as much as 0·010; beyond 8 there are only three weakly determined points. The curve was for most plates not used beyond $h = 7$; in comparatively few cases were values beyond $h = 7{\cdot}5$ needed. The average deviation of individual points from the wedge calibration curve is about 0·015 in log I.

Reduction of Plates.—Microphotometer tracings of the spectra were measured and reduced in the usual manner. The tracings, with very few exceptions, were made with magnification 50 and were measured at plate intervals of 0·1 mm. (in a few cases 0·05 mm.), and in addition readings were

* This is not always so. See, for instance, Plaskett's work, *M.N.*, **91**, 870, 1931.

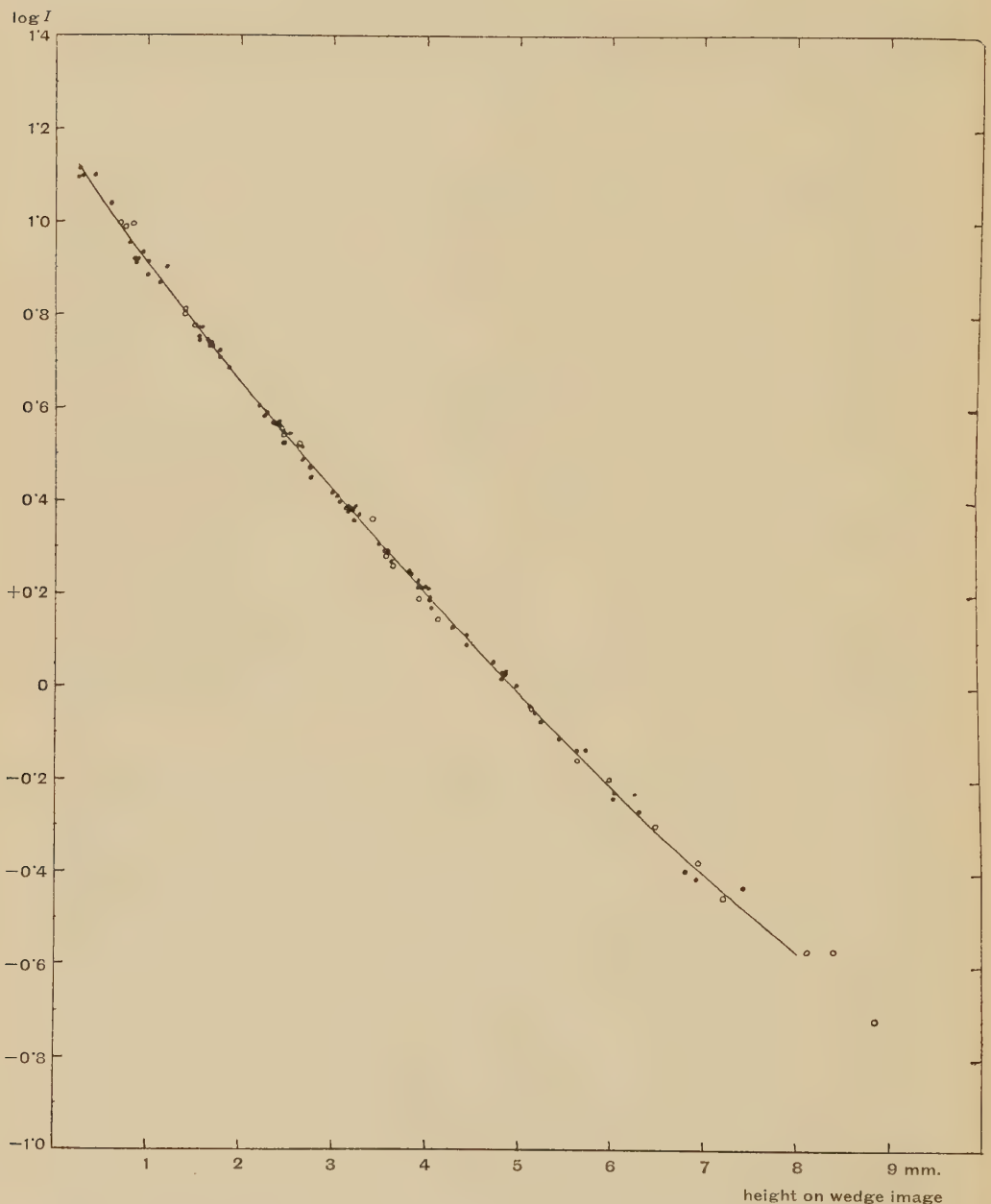

FIG. 1.—*Result of wedge calibration. Ordinates are log (intensity) ; abscissæ are heights on the wedge image at λ 4227 in the calibrating spectrograph. Filled circles are from the variable slit method ; open circles from diaphragms.*

taken at each minimum on the tracing. In general, readings over 95 per cent. or under 5 per cent. were not used. One thus worked only in the most favourable density range of the plate. Each plate covered only a part of the calcium line, the centre if heavily exposed, the wings if lightly exposed, and the final profile depends on fitting these together. The positions of the readings in wave-length can be determined from the positions of the line minima, which were measured on every tracing. The intensities were left expressed in logarithms, so that in fitting together all that had to be done was to determine for each plate the constant which must be added to log I to bring the curves together as nearly as possible.

This method of combining the results from different plates gives approximately constant residuals in log I for all points of the line. In intensities therefore the residuals are proportional to the intensities themselves, so that in a sense we are giving preference to the line centre at the expense of the wings.

The position of the continuous background is difficult to determine with accuracy, although, fortunately, the central intensity is comparatively little affected by uncertainty on this point. The extreme wings of the line cannot be affected appreciably by scattered light, so that to determine their position the plates taken without the monochromator were chiefly relied on. There is then no danger of error arising from distortion of the background by the monochromator, however far from the line centre one goes. The chief difficulty arises from the large number of blended lines in the vicinity. Some of these are very noticeable when represented on a logarithmic scale, as in fig. 2 ; on a plain intensity scale (fig. 3) they are even more prominent. It seems to be a matter for some judgment—or guesswork—how far to extend the wings of the calcium line. We may be fairly certain, however, that they extend at least 2·5 or 3 A. from the line centre. The width of the line at intensity 50 per cent. is 0·93 A. The equivalent width of the whole line is 1·32 A., but this figure depends on the assumed extent of the line wings and also on the way the numerous blended lines are smoothed over.

Profile of λ 4227.—The figures just quoted rely on the profile determined with the monochromator, the plates without the monochromator being used only to help with the extreme line wings. A complete profile was also determined quite independently from the plates without the monochromator (fig. 4). There is very satisfactory agreement between the two profiles (fig. 5), except at the line centre, where the monochromator plates gave log $I = 0{\cdot}68$ ($I = 4{\cdot}8$ per cent.) and the others log $I = 0{\cdot}90$ ($I = 7{\cdot}9$ per cent.). In view of the nature of the spectrograph, we may confidently attribute this difference to scattered light within the instrument. The size of the difference, however, shows us that with a prism instrument the range of spectrum transmitted by the monochromator need not be very small. In this region of the spectrum and with this instrument scattered light appears to be negligible if a range of about 30 A. in wave-length is admitted to the spectrograph. With more precautions taken against scatter, by diaphragms, etc. within the spectrograph itself, probably more light still can safely be admitted.

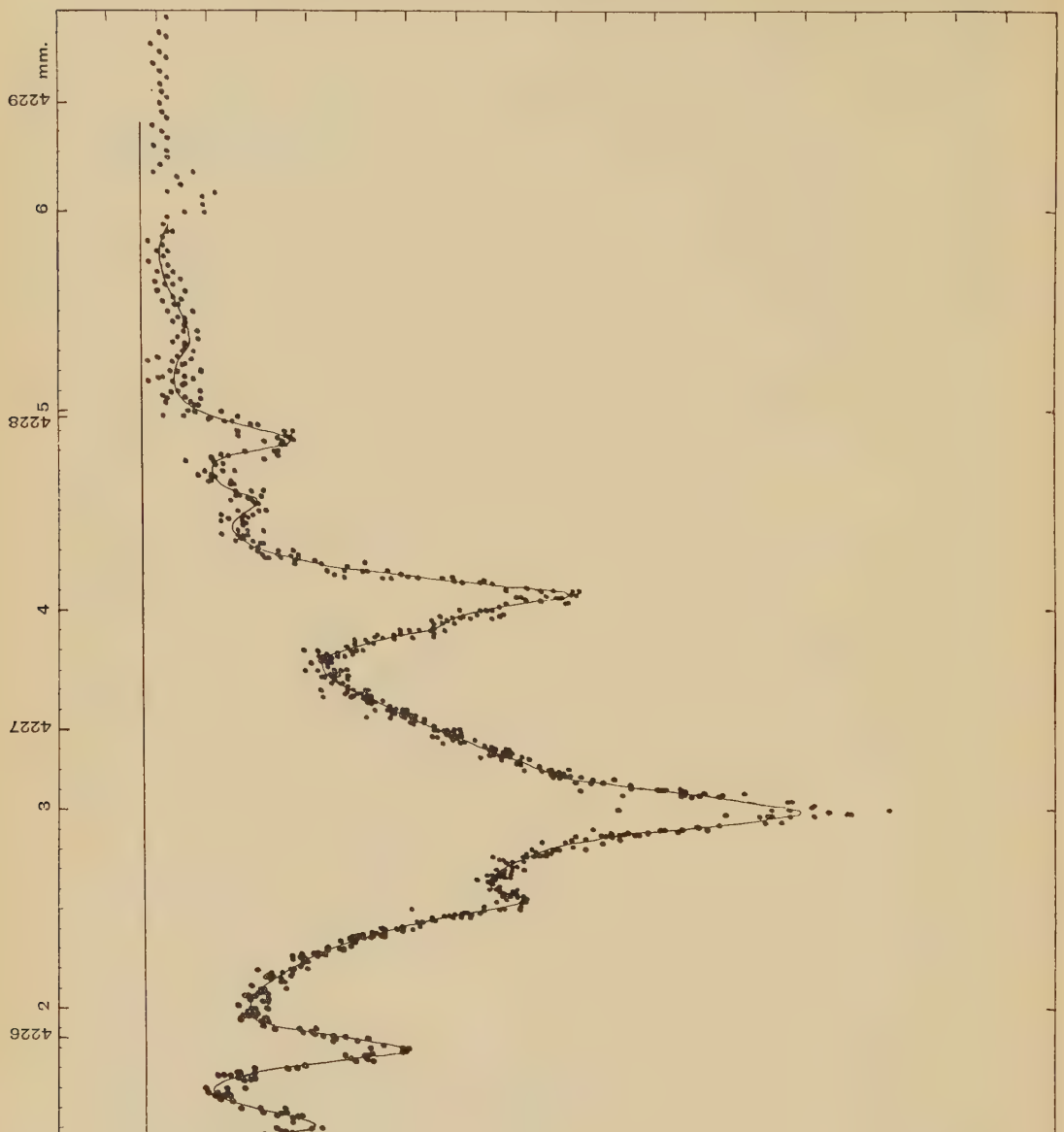

FIG. 2.—*The profile of the central part of λ 4227, as observed with monochromator. Ordinates are log (intensity), abscissæ are mm. on the spectrum as*

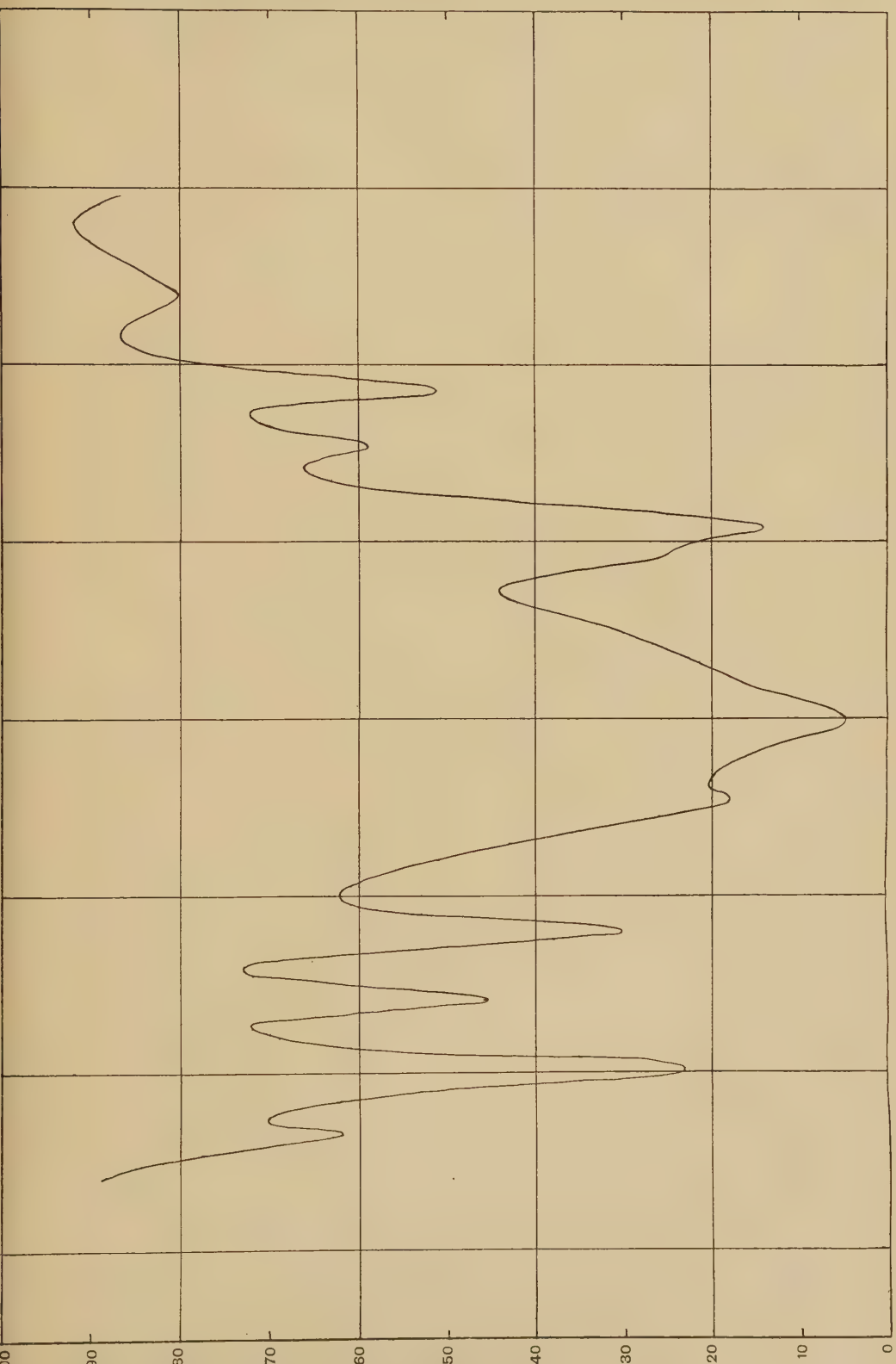

FIG. 3.—*Profile taken from preceding figure, with ordinates* intensities *instead of log (intensity). Ordinates are percentages of the continuous spectrum and are not corrected for instrumental distortion.*

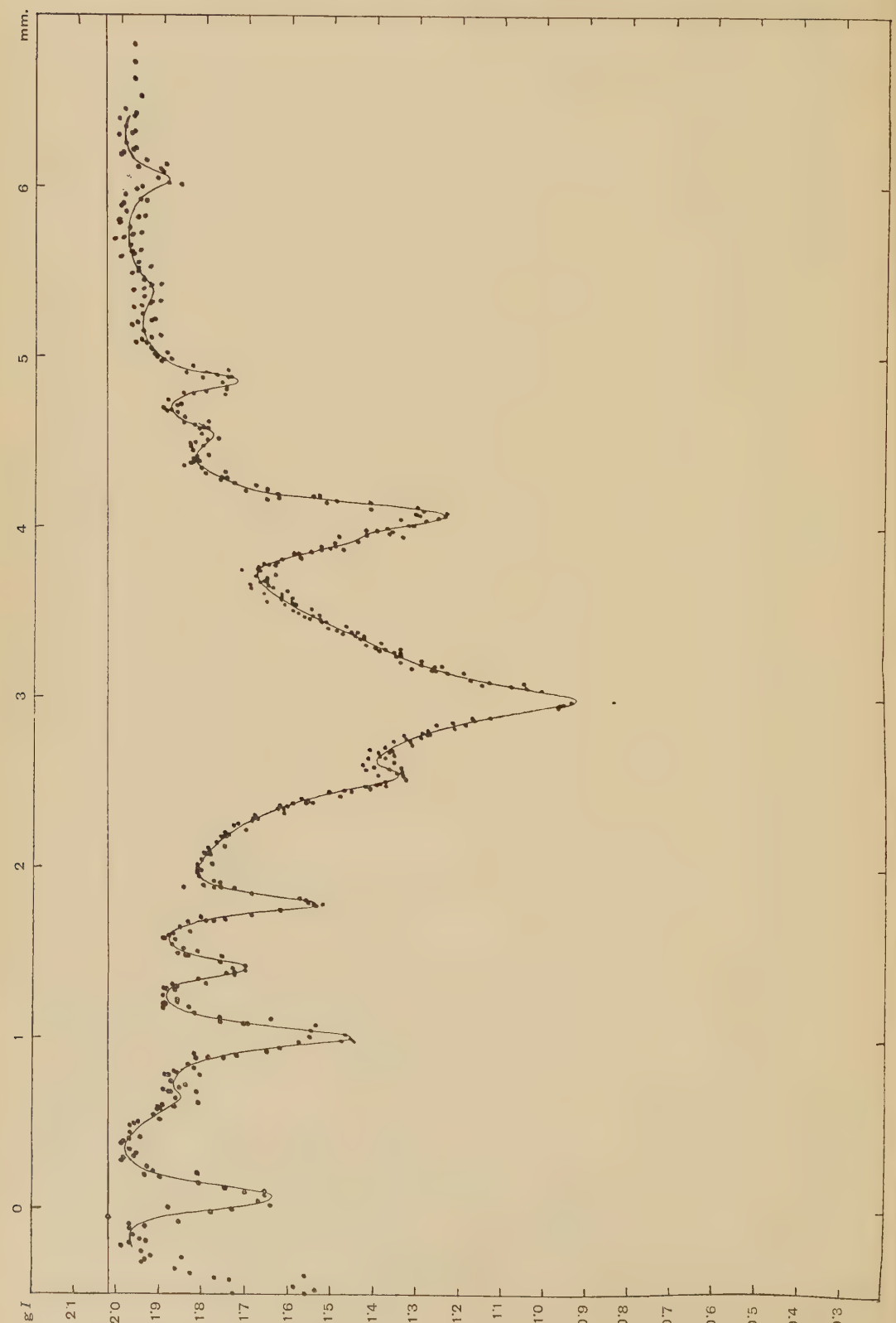

FIG. 4.—*Profile determined without monochromator.*

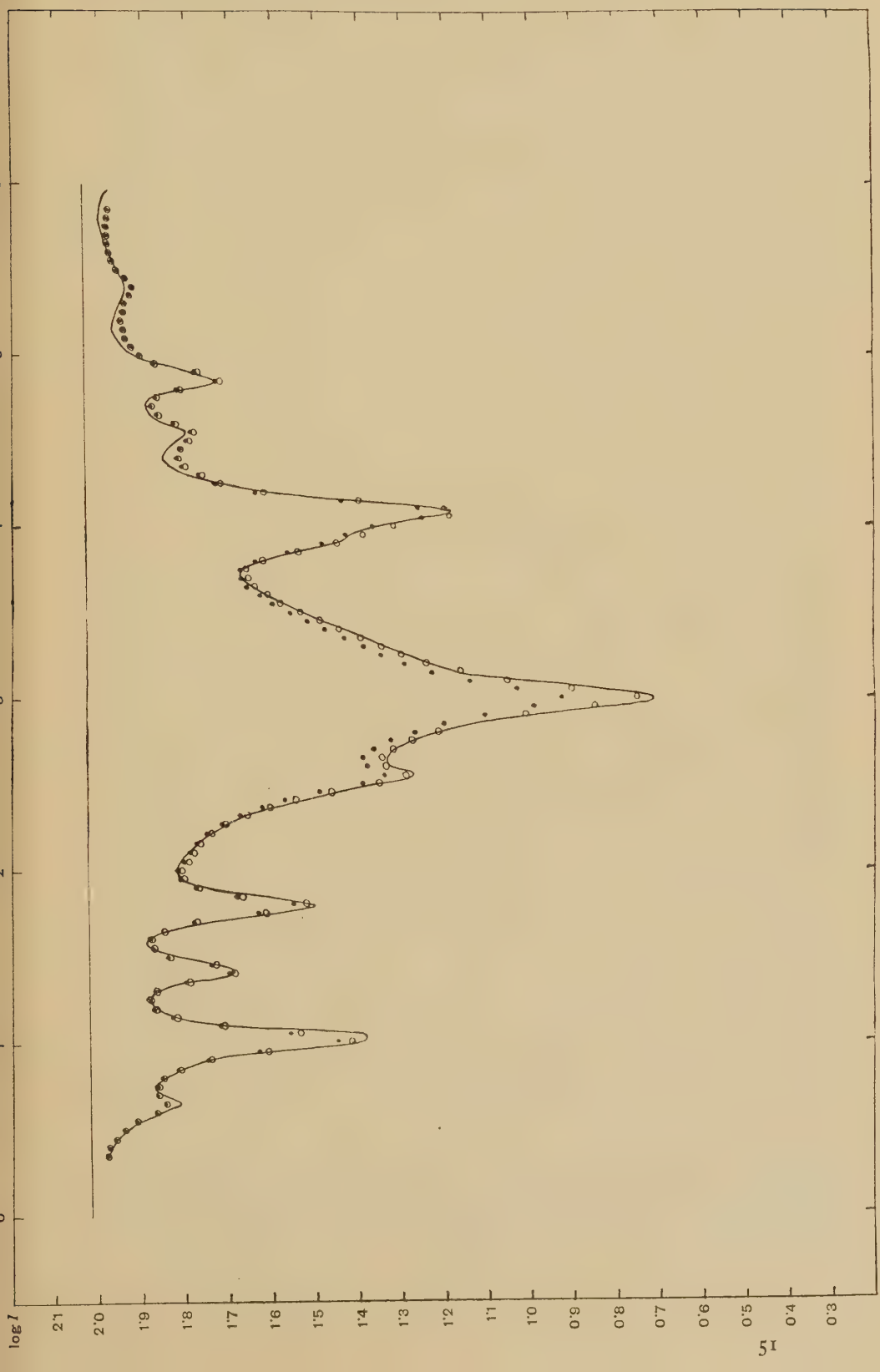

FIG. 5.—*Continuous line is profile determined with monochromator. The filled circles are from the profile determined without monochromator. The unfilled circles are the same points corrected for 3 per cent. scattered light.*

We must remember, however, that if we were working in a region of low plate sensitivity, or where there is strong absorption in the spectrograph, the elimination of unused parts of the spectrum would have to be more thorough. For instance, we might expect narrower slits to be needed on the monochromator when working above 6500 A. with ordinary panchromatic plates, or, again, in the *K* region when there is much glass in the light path.

The agreement between the two independently determined profiles, with and without monochromator, is very clear if the assumption is made that when no monochromator is used there is light uniformly scattered over the plate of intensity 3 per cent. of the continuous spectrum. The observed profile may then be corrected and is in very satisfactory agreement with the profile obtained with the monochromator (fig. 5).

Correction for Finite Resolving Power.—The theoretical resolving power of the McClean spectrograph in this region of the spectrum is about 186,000, and it seems at first sight that a comparatively broad line such as λ 4227 would not be distorted by the spectrograph to any significant extent. However, it was suspected that the effective resolving power of the instrument was well below the theoretical value, so that the determination of the instrumental profile for very narrow lines was undertaken, using the same slit width as for the solar spectrum.

The first step was to photograph the lines near λ 4200 given by an argon discharge tube. The theoretical line width for these, when produced at room temperature, is 0·01 A., a value which is confirmed by observation.* A few photographs quickly showed that the instrumental width was much broader than this. These lines are not very bright, and it needed several hours' exposure to show the outer parts of the line image. Despite many attempts, no exposure of this length could be made successfully, on account of shifts due to temperature changes in the room. Thus, after everything possible had been done with argon, the spectrograph was adjusted for the red neon lines $\lambda\lambda$ 6266–6402, and the instrumental profiles measured for these. Their theoretical width is 0·02 A., agreeing with observation, while there is a line due to the second isotope of neon about 0·03 A. from and about $\frac{1}{10}$ the strength of the main line. Neither the theoretical width nor the isotope line is of importance in view of the observed width due to the instrument, which in terms of millimetres on the plate was slightly less than the value for argon. The agreement is so close that it may be assumed that the linear dimensions of the instrumental profile do not change with wave-length, the slightly greater size given by the argon measures being attributed to small temperature shifts. The neon measures, on account of the much brighter lines, could be extended to 1·5 mm. from the line centre, very much further than those from argon.

It is desirable to avoid any appearance of over-correction to our observed

* I am indebted to Mr. C. V. Jackson for the information quoted here and later concerning the spectra of argon and of neon. He informs me that the krypton spectrum would probably be most suitable for determining the resolving power of a spectrograph. Unfortunately no krypton tube was available at the Observatory while the work was being done.

central intensities and so the neon measures have been taken to apply to λ 4227, when regarded in terms of mm. on the plate. The values for the instrumental profile are given in Table III and illustrated in fig. 6. The effective resolving power of the instrument is about 66,000 at λ 4227, or roughly one-third of the theoretical value. It must be mentioned, however, that the observed instrumental profile includes the effect of photographic spread.* (The plates were backed, of course.) It is perhaps not surprising that the performance of this instrument should be below theoretical standard, in view of the fact that it has 12 optical surfaces, 11 of which are used twice, but later investigation has shown that the 30° prism is mostly to blame. It is hoped that by improvement here the standard of performance of the whole instrument may be raised very appreciably.

If the real profile of a spectrum line be denoted by $L(x)$, x being distance measured along the spectrum, on the plate, and the instrumental profile for an infinitely narrow line be denoted by $I(x)$, the observed profile will be

$$O(x) = \int_{-\infty}^{+\infty} L(\xi) I(x - \xi) d\xi.$$

If $L(x)$ and $I(x)$ can be expressed sufficiently accurately in terms of simple algebraic functions, it is usually possible to perform the integration algebraically. In the present case, however, it was found more satisfactory to resort to numerical integration. It was found that an assumed profile, agreeing in general closely with the observed profile but with central intensity 2 per cent., predicted an observed profile with central intensity 4·9 per cent. An assumed true central intensity 2·5 per cent. gave an observed profile with central intensity 5·5 per cent. An estimate has been made of the effect of those parts of the instrumental profile lying beyond the furthest point measured on the neon plates. Assuming the intensity from there onwards falls off as the square of the distance from the centre (in fair agreement with the outer measures), there is a contribution of about 0·1 per cent. to the central intensity, and the figures just quoted should be raised by this amount. We may say therefore that our observations (measured intensity 4·8 per cent.) show a true central intensity a little less than 2 per cent. It is more likely that we have slightly underestimated the effect of instrumental distortion than otherwise.

In the work mentioned above Thackeray observed a central intensity 3·6 per cent. (based on two plates only), and a footnote to his paper states that this is affected by less than 0·5 per cent. by instrumental distortion. This estimate is due to a rough calculation made by the present writer, who must take complete responsibility for it. Actually it considerably underestimates the effect of the instrumental profile by not taking sufficient account of the regions far removed from the line centre. Mr. Allen has

* Thus here the photographic spread arises chiefly from scattering in the emulsion, which is unaffected by backing the plate. The observed instrumental profile, as used below, should correct for this, provided the emulsion scatter is the same for the plates used at λ 4200 and those used at λ 6500. The effective resolving power is thus rather less than the true resolving power.

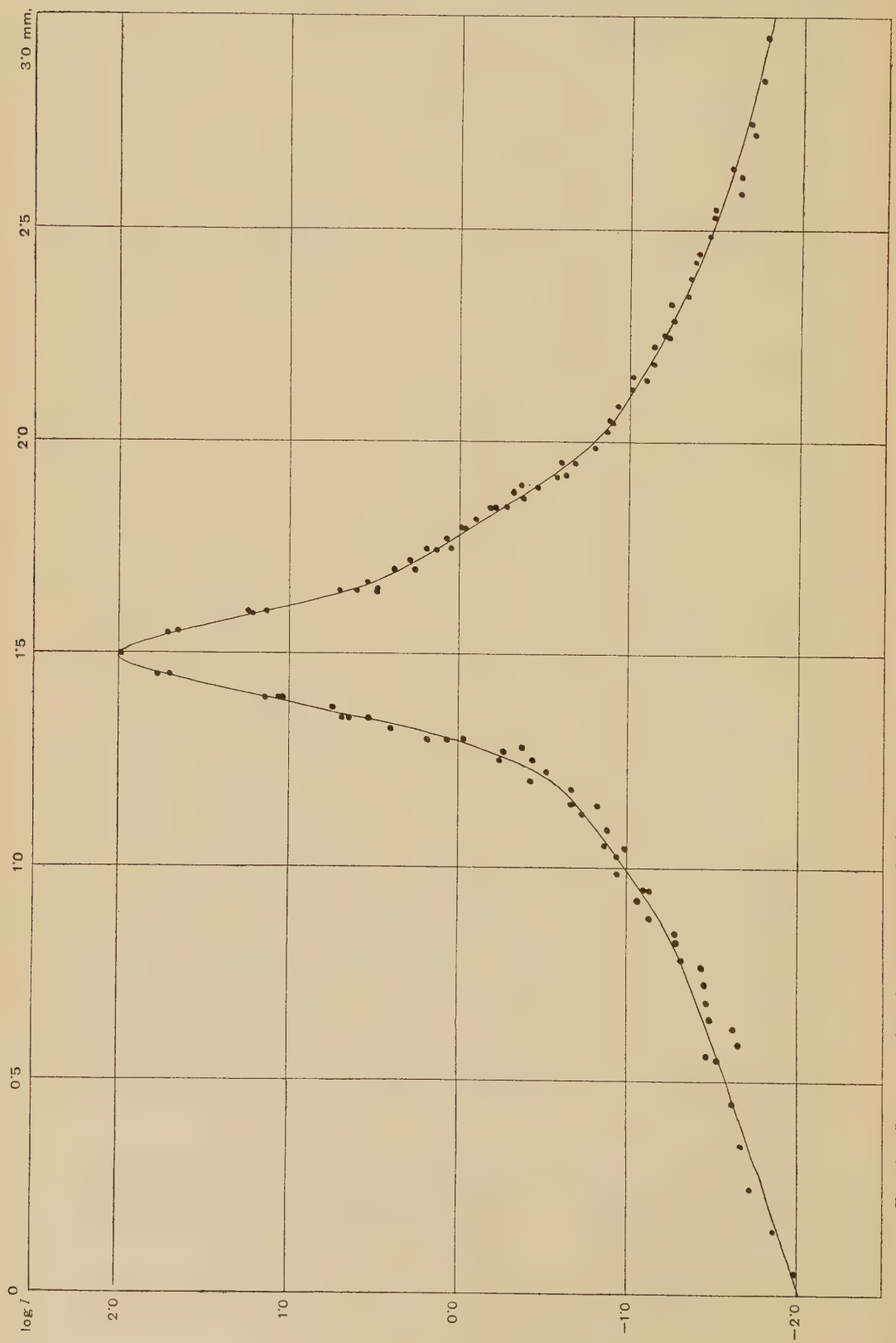

FIG. 6.—*Instrumental profile given by the McClean prism spectrograph with very narrow (neon) lines. Ordinates are log (intensity);*

emphasized in conversation the need for taking full account of this region, since the intensity in the profile falls off on the average only as the square of the distance from the centre. Assuming a true central intensity 2 per cent. and that the instrumental profile given by the Rowland grating has the theoretical shape, a more careful calculation shows that the observed central intensity should have been about 5 per cent. Since measurements made very recently by Allen have shown that the instrumental profile of this grating is wider than the theoretical value (as it seems to be in the majority of instruments), Thackeray's central intensity, corrected for finite resolving power, must be near zero. His measurements, however, are affected by the fact that he used the earlier wedge calibration mentioned above (p. 743) and therefore makes his central intensities rather too black. There is then nothing in his measures to contradict the results of this paper. It should be emphasized that none of this criticism affects Thackeray's work in its principal aim, which was to show the value of a monochromator in the task of determining line profiles. In any case his central intensities appear to be substantially correct.

Probable Error of Central Intensity.—It is a matter of the greatest difficulty to make any precise estimate of the error of the central intensity given here for λ 4227. An approximate idea may be gained from the following considerations. Owing to the large number of plates taken, the accidental error should be comparatively small. The mean error for log I at the centre, judging from the inter-agreement of actual measures there, is 0·03, which corresponds to a mean error in intensity of about 0·3 per cent. But since these centre values are linked to the continuous background through measures made on other plates, the mean accidental error is likely to be somewhat greater than this—say $\sqrt{2}$ times as great.

There will in addition be systematic errors arising from errors in the wedge calibration and possibly from Eberhard effect. The latter, on account of the big scale of the spectra and the absence of positive evidence for its presence, may be neglected. With regard to the wedge a precise estimate of error is very difficult, since different parts of the wedge were used on different plates. We estimate this error provisionally as 0·3 per cent., a figure higher than the wedge calibration observations by themselves suggest.

The error arising in the correction for resolving power we estimate as 0·4 per cent. This is probably the greatest single source of error. The total error, supposing all these sources to be independent, is then about 0·65 per cent. As far as internal evidence goes, we seem justified in putting our *probable error* at 0·7 per cent., unless other sources of systematic error can be disclosed.

The Central Intensities of Fraunhofer Lines.—We have seen that there is good evidence to suppose that the central intensity of λ 4227 is only 2 per cent. of the adjacent continuous spectrum. This value is considerably lower than 10 per cent., the figure very frequently quoted as typical for Fraunhofer lines, and it is pertinent to inquire first whether with sufficiently careful measures other lines would also come down to 2 per cent., and

secondly whether with still more refined methods the 2 per cent. would be found to be too high and the real central intensities still nearer zero.

A recent publication by Allen * gives the results of measures of a large number of lines in the solar spectrum, the work being carried out with a prism spectrograph. He gives central intensities, corrected for instrumental distortion, for many of these lines, and these values appear to be among the most reliable yet published. Certainly they are to be regarded with a great deal more confidence than values obtained with grating instruments, where no proper investigation into instrumental distortion has been made. An inspection of his table shows that such lines as those of the hydrogen Balmer series, or the magnesium *b* lines, have central intensities well above 10 per cent., while certain other lines, such as the *D* lines of sodium and the neutral iron lines $\lambda\lambda$ 4383, 4046, have central intensities only 3 or 4 per cent. Allen did not use a monochromator, and it is conceivable that his figures are a little affected by scattered light. However, his work shows that doubtless there are certain lines of the solar spectrum with central intensities around 2 to 4 per cent. We may note that the lines concerned are low-level lines from neutral atoms. The marked differences in structure of Fraunhofer lines are becoming clearer as measures become more accurate, and it seems that the time is ripe for a classification of solar lines, not merely according to total intensity, but according to depth.

Will the central intensities of certain selected Fraunhofer lines, when measures are made with still more accuracy, be found to be less than 2 per cent. and very little above zero? Probably not. The ordinary theories of formation of absorption lines predict practically perfectly black centres, but apart from the complications of atomic structure there are noteworthy departures in reality from the idealized conditions under which Fraunhofer lines are formed in theory, particularly with regard to the structure of the Sun's surface. This is by no means composed of homogeneous static layers. On the contrary, the outstanding characteristic of the solar surface is the amount of irregularity and movement on it, so that we can scarcely expect theoretically black line centres.

The constant changes and eruptions are best seen on the Sun by observations in monochromatic light, with spectroheliograph or spectrohelioscope. These instruments generally utilize light from the centre of a selected absorption line. Hence the bright markings characteristic of spectroheliograms are nothing more or less than a record of central intensity changes of a given line when observed over the whole disc. It is true that, unless special precautions are taken, a spectroheliogram will include light not merely from the precise centre of the line but also from other surrounding parts, but we have no reason to suppose that the typical appearance of a spectroheliogram, its bright and dark markings, would disappear if we could work with strictly monochromatic light from the line centre. At several observatories spectroheliograms have been taken in the light of λ 4227. Those published from Meudon † show the granular markings

* *Memoirs of the Commonwealth Solar Observatory*, No. 5, 1934.

† *Meudon Annales*, **8**, 68, 1930.

or flocculi which are found in the more familiar photographs in the light of *Hα* or *K*. In other words, the central intensity of λ 4227 undergoes changes from point to point of the disc—unless we are prepared to suppose that the variations of brightness on the disc are due to bodily shifts of the whole line, from motion in the line of sight. We know also that in general the bright flocculi are most numerous where disturbances on the solar surface are greatest, *i.e.* that the line centre is brightest and deviates most from the ideal zero intensity where the surface conditions deviate most from the ideal theoretical state. We remember that in our measures of λ 4227 the spectrograph slit covered an appreciable area of the solar disc, which may be expected to have included a typical selection of the disturbances shown by spectroheliograms. This area was of the order of 100 square seconds of arc (taking into account the width of spectrum measured on the photometer), with some small admixture of light from adjacent areas, scattered into the beam by the Earth's atmosphere or the telescope. It is possible that had the instrumental arrangements permitted the selection of a smaller area we could have obtained a somewhat smaller central intensity at some points of the disc.

Finally, we may mention that the whole of the observed 2 per cent. at the centre of λ 4227 can be accounted for on the hypothesis that we have a perfectly black line centre produced by each small area of the disc, but that each area has a random motion in the line of sight of average velocity 1·5 km./sec., the observed line being the mean from a large number of such areas. Whether such a hypothesis would derive support from spectroscopic examination of, say, individual "rice-grains" on the surface cannot be decided on the basis of existing observations.

TABLE I

Data regarding lines in the neighbourhood of λ 4227. The first three columns are copied from the Revised Rowland Catalogue. The last two columns refer to intensities uncorrected for instrumental distortion.

Line	Identification	Rowland Intensity	Position in Fig. 2 (mm.)	Minimum Log (intensity) in Fig. 2	Minimum Intensity as Percentage of Background
4224·461		0			
4224·515	Fe, Cr	3			
4224·634	Fe	−1			
4224·862	CH	2N	0·06	1·612	39
4225·048		−2			
4225·220	V^+	0	0·65	1·817	62
4225·332	Pr^+? Sa^+	−2			
4225·463	Fe	3	1·01	1·380	23
4225·717		1	1·41	1·682	46
4225·813		−2			

Line	Identification	Rowland Intensity	Position in Fig. 2 (mm.)	Minimum Log (intensity) in Fig. 2	Minimum Intensity as Percentage of Background
4225·964	Fe	2	1·79	1·504	30
4226·082		−2			
4226·224		−2			
4226·353		0			
4226·433	Fe	2	2·55	1·272	18
4226·567	Ge	0			
4226·742	Ca	20*d*	2·99	0·705	4·8
4226·972		1*d* ?			
4227·159		−1N			
4227·317	−Ti^{+}	1N			
4227·442	Fe	4	4·08	1·177	14
4227·665	Ti	−1			
4227·760	Ce^{+} Zr	0	4·57	1·801	59
4227·946		1N	4·86	1·737	51
4228·108		−2			
4228·318		−1N	5·4	1·937	80
4228·559		−2			
4228·722		1			
4228·876	Co ?	−2			

TABLE II

Distribution of intensity in the solar spectrum near λ 4227, as given by measures with monochromator. (*Scale is 0·64 A./mm.*)

Position on Plate (mm.)	Log (intensity) Line	Log (intensity) Back-ground	Intensity as per cent. of Back-ground	Position on Plate (mm.)	Log (intensity) Line	Log (intensity) Back-ground	Intensity as per cent. of Back-ground
0·40	1·97	2·021	89	1·00	1·40	2·023	24
·45	1·96		87	·05	1·44		26
·50	1·935		82	·10	1·71		49
·55	1·90		76	·15	1·81		61
·60	1·86	2·022	69	·20	1·86		69
·65	1·815		62	·25	1·88		72
·70	1·855		68	·30	1·865		69
·75	1·87		70	·35	1·795		59
·80	1·85		67	·40	1·69	2·024	46
·85	1·81		61	·45	1·72		50
·90	1·75		53	·50	1·805		60
·95	1·57		35	·55	1·88		72

Position on Plate (mm.)	Log (intensity) Line	Log (intensity) Back-ground	Intensity as per cent. of Back-ground	Position on Plate (mm.)	Log (intensity) Line	Log (intensity) Back-ground	Intensity as per cent. of Back-ground
1·60	1·885		73	3·80	1·62	2·030	39
·65	1·84		65	·85	1·55		33
·70	1·75		53	·90	1·45		26
·75	1·60		38	·95	1·42		25
·80	1·51	2·025	31	4·00	1·35		21
·85	1·615		39	·05	1·22		15
·90	1·75		53	·10	1·21		15
·95	1·81		61	·15	1·43		25
2·00	1·815		62	·20	1·59	2·031	36
·05	1·81		61	·25	1·72		49
·10	1·79		58	·30	1·795		58
·15	1·77		56	·35	1·83		63
·20	1·735	2·026	51	·40	1·85		66
·25	1·70		47	·45	1·845		65
·30	1·66		43	·50	1·82		62
·35	1·595		37	·55	1·80		59
·40	1·52		31	·60	1·85	2·032	66
·45	1·44		26	·65	1·88		70
·50	1·33		20	·70	1·89		72
·55	1·27		18	·75	1·88		70
·60	1·33	2·027	20	·80	1·81		60
·65	1·335		20	·85	1·735		50
·70	1·31		19	·90	1·78		56
·75	1·265		17	·95	1·86		67
·80	1·22		16	5·00	1·92	2·033	77
·85	1·12		12	·05	1·95		83
·90	0·95		8·4	·10	1·96		85
·95	0·78		5·7	·15	1·97		87
3·00	0·72	2·028	4·8	·20	1·965		86
·05	0·85		6·6	·25	1·96		85
·10	1·005		9·5	·30	1·95		83
·15	1·17		14	·35	1·94		81
·20	1·235		16	·40	1·94	2·034	81
·25	1·285		18	·45	1·945		81
·30	1·345		21	·50	1·96		84
·35	1·39		23	·55	1·965		85
·40	1·435	2·029	25	·60	1·98		88
·45	1·49		29	·65	1·985		89
·50	1·53		32	·70	1·99		90
·55	1·57		35	·75	1·995		91
·60	1·61		38	·80	2·00	2·035	92
·65	1·65		42	·85	1·995		91
·70	1·67		44	·90	1·985		89
·75	1·665		43	·95	1·975		87

TABLE III

Instrumental profile of McClean prism spectrograph, given by measures of neon lines (in direction of increasing wave-length)

Position on Plate (mm.)	Log (intensity)	Position on Plate (mm.)	Log (intensity)
−1·5	−2·00	+·15	+0·67
1·45	−1·97	·2	+0·33
1·4	−1·93	·25	+0·13
1·35	−1·88	·3	−0·09
1·3	−1·85	·35	−0·26
1·25	−1·80	·4	−0·45
1·2	−1·76	·45	−0·64
1·15	−1·72	·5	−0·79
1·1	−1·68	·55	−0·90
1·05	−1·63	·6	−0·99
1·0	−1·59	·65	−1·07
·95	−1·55	·7	−1·14
·9	−1·50	·75	−1·20
·85	−1·45	·8	−1·26
·8	−1·40	·85	−1·32
·75	−1·35	·9	−1·38
·7	−1·30	·95	−1·43
·65	−1·23	1·00	−1·48
·6	−1·15	1·05	−1·53
·55	−1·07	1·1	−1·57
·5	−0·99	1·15	−1·61
·45	−0·90	1·2	−1·65
·4	−0·81	1·25	−1·68
·35	−0·71	1·3	−1·70
·3	−0·57	1·35	−1·74
·25	−0·32	1·4	−1·77
·2	+0·04	1·45	−1·80
·15	+0·55	1·5	−1·83
·1	+1·10		
−0·05	+1·70		
0·00	+2·00		
+0·05	+1·68		
·1	+1·15		

The writer wishes to express his thanks for the assistance of Mr. Moss in setting up the monochromator and of Mr. E. Shirley in the numerical computations. Professor H. H. Plaskett has been kind enough to read the paper and suggest a few criticisms.

MEAN AREAS AND HELIOGRAPHIC LATITUDES OF SUNSPOTS IN THE YEAR 1934.

Royal Observatory, Greenwich.

(Communicated by the Astronomer Royal)

The following results are in continuation of those given in *M.N.*, **94**, 869, 1934, and are derived from the measurement at Greenwich of photographs taken at the Royal Observatories of Greenwich and the Cape, and at the Kodaikanal Observatory, India.

Table I gives the mean daily areas of umbræ, whole spots and faculæ for each synodic rotation of the Sun included in the year 1934; the means for the year as a whole are given in Table II.

TABLE I

No. of Rotation	Rotation Commenced U.T.	Days photographed	Mean Daily Areas: Projected *			Mean Daily Areas: Corrected for Foreshortening †		
			Umbræ	Whole Spots	Faculæ	Umbræ	Whole Spots	Faculæ
1074	1933 Dec. 27·30	28	6	32	33	7	37	50
1075	1934 Jan. 23·64	27	20	87	206	16	71	240
1076	Feb. 19·98	27	5	21	196	3	12	234
1077	Mar. 19·30	28	6	28	129	8	49	166
1078	Apr. 15·59	27	93	503	291	72	399	357
1079	May 12·83	27	76	437	587	63	376	676
1080	Jun. 9·04	27	30	154	391	21	111	463
1081	July 6·23	28	28	142	514	22	117	610
1082	Aug. 2·44	27	25	137	348	20	111	403
1083	29·68	27	4	14	341	5	19	402
1084	Sept. 25·94	27	6	18	248	5	16	305
1085	Oct. 23·23	28	15	83	178	12	72	221
1086	Nov. 19·54	27	16	86	208	18	92	253
1087	Dec. 16·85	27	68	325	587	51	249	699

* Expressed in millionths of the Sun's disc.

† Expressed in millionths of the Sun's hemisphere.

TABLE II

Year	No. of Days: Photographed	No. of Days: Without Spots	Mean Daily Areas: Projected * Umbræ	Projected * Whole Spots	Projected * Faculæ	Corrected for Foreshortening † Umbræ	Corrected for Foreshortening † Whole Spots	Corrected for Foreshortening † Faculæ
1933	365	234	24	120	225	18	88	267
1934	365	145	27	142	297	22	119	354

* Expressed in millionths of the Sun's disc.

† Expressed in millionths of the Sun's hemisphere.

Table III gives for each rotation in the year 1934 the mean daily area of the whole spots (corrected for foreshortening) and the mean heliographic latitude of the spotted areas for both northern and southern hemispheres. The mean heliographic latitude of the entire spotted area and the mean distance from the equator of all spots are also tabulated. The mean value for the year 1934 is given in Table IV, which also gives the mean latitudes relative to the old cycle spots and the new cycle spots.

TABLE III

No. of Rotation	Rotation Commenced U.T.	Spots North of the Equator		Spots South of the Equator		Mean Latitude of entire Spotted Area	Mean Distance from Equator of all Spots
		Mean Daily Area	Mean Heliographic Latitude	Mean Daily Area	Mean Heliographic Latitude		
			°		°	°	°
1074	1933 Dec. 27·30	37	4·69	0	...	+ 4·69	4·69
1075	1934 Jan. 23·64	67	15·80	4	23·26	+13·76	16·19
1076	Feb. 19·98	0·3	23·43	12	10·61	− 9·88	10·88
1077	Mar. 19·30	11	27·49	38	28·75	−16·56	28·48
1078	Apr. 15·59	6	19·84	393	27·91	−27·19	27·79
1079	May 12·83	119	26·30	257	30·77	−12·67	29·36
1080	June 9·04	105	2·90	6	29·84	+ 1·15	4·34
1081	July 6·23	112	18·32	5	30·15	+16·30	18·82
1082	Aug. 2·44	9	4·43	101	29·18	−26·30	27·06
1083	29·68	17	7·63	2	24·52	+ 3·65	9·72
1084	Sept. 25·94	4	23·23	13	22·81	−12·49	22·91
1085	Oct. 23·23	71	21·44	0·5	22·43	+21·14	21·45
1086	Nov. 19·54	0·4	18·08	92	24·26	−24·06	24·23
1087	Dec. 16·85	31	25·32	218	27·99	−21·25	27·65

TABLE IV

Year	Days Photographed	Spots North of the Equator		Spots South of the Equator		Mean Latitude of entire Spotted Area	Mean Distance from Equator of all Spots
		Mean Daily Area	Mean Heliographic Latitude	Mean Daily Area	Mean Heliographic Latitude		
			°		°	°	°
1933	365	86	10·60	2	8·35	+10·23	10·56
1934	365	44	16·45	74	28·09	−11·49	23·75
1934	Old Cycle	19	4·10	1	4·37	+ 3·79	4·11
	New Cycle	26	25·44	74	28·31	−14·46	27·57

Tables II and IV are in continuation of similar tables given in *Monthly Notices*: for the years 1874 to 1888—**49**, 381–382; 1889 to 1902—**63**, 465–466; 1901 to 1914—**76**, 402–403; 1913 to 1924—**85**, 1007–1008; 1923 to 1933—**94**, 870–871.

The rotations in Tables I and III are numbered in continuation of Carrington's series.

The chief features of the record of sunspots and faculæ for the year 1934 are as follows :—

1. The diminishing frequency of sunspots in the equatorial belt and the increasing frequency of spots in higher latitudes denote the passing of minimum conditions of solar activity and the commencement of another 11-year cycle.

2. On 145 days no spots were recorded and on 69 days no faculæ. On 44 days the disc was entirely blank. The corresponding numbers for the year 1933 were 234, 123 and 105 days respectively.

3. The old cycle spots were chiefly in the northern hemisphere, which had been the more active hemisphere for eight out of the ten years of the preceding cycle (1924 to 1933). The new cycle spots of 1934 showed a preference for the southern hemisphere, and it will be of interest to see whether this preference is maintained during the coming cycle.

4. The mean latitude of all spots, irrespective of sign, is nearly 24° (as compared with $10\frac{1}{2}°$ for the previous year). Separation of the spots according to new and old cycles gives mean latitudes of $27\frac{1}{2}°$ and 4° respectively. The highest latitude recorded for a spot during the year was $-34°$.

5. The number of groups lasting for two days or longer was 55 ; of these, 23 were in the northern hemisphere and 32 in the southern. In addition, there were 25 very small groups recorded on one day only ; 6 were north and 19 south of the equator.

Royal Observatory, Greenwich :
1935 *October* 14.

OCCULTATIONS OF STARS BY THE MOON OBSERVED AT BIRMINGHAM UNIVERSITY DURING THE YEAR 1934.

James Young.

This report continues those of previous years.

Table I gives particulars of the observations. The practice of making a correction of about $-0^s.3$ for lag has been discontinued. Three stars were unidentified.

Table II gives the reductions. The usual correction of $0^h.0025$ was made to the U.Ts. for the purpose of taking the Moon's right ascension, declination and parallax from the *Nautical Almanac*. As reliable positions were not immediately available for Nos. 92, 100 and 101, reductions of these occultations were not attempted.

Table III gives the positions of stars not in the *Nautical Almanac*, together with the authorities used in obtaining these positions.

TABLE I

No.	Star	Mag.	Phase	Date	U.T.
				d	h m s
89	A Leo	4·6	R	Jan. 05	00 29 03·5
90	B.D. +0° 5039	8·9	D	Jan. 19	18 23 30·6
91	B.D. +0° 5038	9·0	D	Jan. 19	18 34 03·3
92	B.D. +6° 72	8·4	D	Jan. 20	20 33 20·3
93	47 B Ari	6·5	D	Jan. 22	18 00 41·0
94	B.D. +24° 583	6·9	D	Jan. 24	18 47 44·4
95	B.D. +24° 587	6·8	D	Jan. 24	19 11 27·8
96	B.D. +27° 832	8·5	D	Jan. 26	20 00 35·8
97	B.D. +26° 902	8·7	D	Jan. 26	20 49 23·3
98	B.D. +27° 846	7·8	D	Jan. 26	21 53 58·6
99	B.D. +26° 1254	8·0	D	Jan. 27	18 15 42·8
100	B.D. +15° 273	8·2	D	Feb. 18	19 13 16·8
101	B.D. +18° 297	8·8	D	Mar. 18	19 32 57·2
102	Anon.	(9)	D	Mar. 18	20 06 48·7
103	W.Z.C. 189	6·9	D	Mar. 19	19 00 17·7
104	B.D. +26° 780	7·4	D	Mar. 21	20 31 13·3
105	B.D. +26° 787	8·4	D	Mar. 21	21 18 43·8
106	W.Z.C. 474	6·6	D	Mar. 23	19 44 20·5
107	B.D. +25° 1476	8·7	D	Mar. 23	20 12 33·0
108	B.D. +25° 1479	7·6	D	Mar. 23	20 25 58·9
109	A Leo	4·6	D	Mar. 27	20 29 52·1
110	B.D. +23° 561	6·6	D	Apr. 16	19 48 56·4
111	B.D. +23° 567	7·3	D	Apr. 16	20 09 20·3
112	B.D. +24° 578	7·3	D	Apr. 16	20 14 14·7
113	Anon.	(9)	D	Apr. 16	20 33 10·9
114	B.D. +24° 584	9·2	D	Apr. 16	20 40 01·2
115	Anon.	(9)	D	Apr. 20	20 29 59·9
116	ϕ Sag	3·3	D	Jul. 24	22 46 42·7
117	16 Tau	5·4	D	Aug. 31	00 56 35·6
118	17 Tau	3·8	D	Aug. 31	00 57 47·7
119	q Tau	4·3	D	Aug. 31	01 21 10·1
120	20 Tau	4·1	D	Aug. 31	01 27 38·2
121	17 Tau	3·8	R	Aug. 31	01 50 01·8
122	16 Tau	5·4	R	Aug. 31	02 02 53·9
123	q Tau	4·3	R	Aug. 31	02 16 03·6
124	20 Tau	4·1	R	Aug. 31	02 36 35·7
125	21 Tau	5·8	R	Aug. 31	02 37 21·6
126	22 Tau	6·5	R	Aug. 31	02 44 26·3
127	B.D. +23° 540	6·8	R	Aug. 31	03 11 57·3
128	B.D. +24° 562	6·7	R	Aug. 31	03 18 02·8
129	B.D. +24° 566	7·5	R	Aug. 31	03 32 26·1
130	W.Z.C. 227	6·6	R	Aug. 31	03 43 08·6
131	σ Sag	2·1	D	Sept. 17	20 03 20·7
132	125 Tau	5·1	R	Oct. 26	20 36 37·3
133	ϵ Gem	3·2	D	Oct. 28	00 29 02·0
134	ϵ Gem	3·2	R	Oct. 28	00 37 05·6
135	λ Pis	4·6	D	Dec. 13	19 56 57·1

Notes

97 Very difficult.
117 Bright limb. Difficult.
118 Bright limb.
119 Bright limb.
120 Bright limb.
132 Through thin cloud. Doubtful.
133 Bright limb.
135 Through thin cloud. Certain.

TABLE II

No.	$\sigma'-\sigma$	χ	ρ	$\chi-\rho$
	″	° ′	° ′	° ′
89	+0·4	268 28	115 30	+152 58
90	−0·1	86 09	62 23	+ 23 46
91	−1·3	47 34	62 23	− 14 49
93	−3·1	17 06	68 39	− 51 33
94	−2·3	41 27	78 14	− 36 47
95	−1·8	54 10	78 20	− 24 10
96	−2·5	50 04	90 30	− 40 26
97	−1·8	171 05	90 43	+ 80 22
98	−1·5	86 12	91 00	− 4 48
99	−1·2	39 30	96 11	− 56 41
103	−1·0	73 45	74 44	− 0 59
104	−1·5	161 54	86 47	+ 75 07
105	−2·2	76 20	86 59	− 10 39
106	−0·9	98 31	98 47	− 00 16
107	−0·3	84 42	98 54	− 14 12
108	−1·8	57 42	98 57	− 41 15
109	+1·0	105 42	115 22	− 9 40
110	−1·4	123 19	78 32	+ 44 47
111	+0·3	137 01	78 36	+ 58 25
112	−1·7	99 43	78 38	+ 21 05
114	−3·2	98 23	78 44	+ 19 39
116	− 1·1	137 43	81 25	+ 56 18
117	− 3·7	67 01	78 10	− 11 09
118	− 2·8	108 00	78 11	+ 29 49
119	− 2·4	33 55	78 16	− 44 21
120	− 2·4	67 51	78 18	− 10 27
121	+ 2·0	212 43	78 23	+134 20
122	+ 2·7	253 21	78 26	+174 55
123	+ 2·1	286 08	78 29	−152 21
124	+ 2·6	252 35	78 34	+174 01
125	+ 1·4	294 43	78 34	−143 51
126	+ 1·8	284 28	78 36	−154 08
127	+ 1·0	203 24	78 42	+124 42
128	+ 2·0	265 40	78 44	−173 04
129	+ 1·2	273 55	78 47	−164 52
130	+ 0·4	196 49	78 50	+117 59
131	− 2·6	99 38	80 26	+ 19 12
132	+12·2	249 24	91 13	+158 11
133	+ 0·9	9 17	98 13	− 88 56
134	+ 1·6	356 13	98 15	−102 02
135	− 0·9	110 25	63 33	+ 46 52

TABLE III

No.	$\alpha_{1934\cdot0}$	$\Delta\alpha$	$\delta_{1934\cdot0}$	$\Delta\delta$	Authority
	h m s	s	° ′ ″	″	
90	23 39 51·93	+0·17	+ 0 32 17·1	+ 1·4	Ab, Al, B, Y
91	23 39 51·61	+0·17	+ 0 44 49·2	+ 1·4	Ab, B, Y
94	3 47 27·71	+1·60	+24 57 54·5	+12·6	Ay, G, Y
95	3 48 14·32	+1·60	+24 58 08·8	+12·6	Ay, G, Y
96	5 36 23·95	+2·30	+27 24 30·6	+ 9·1	G, Y
97	5 37 01·52	+2·29	+27 00 44·4	+ 9·0	G, Y
98	5 39 40·75	+2·31	+27 16 01·7	+ 8·9	G, Y
99	6 26 44·24	+2·51	+26 41 23·8	+ 5·9	G, Y
103	3 10 26·36	+0·53	+22 42 30·8	+ 9·4	Ay, Y
104	5 00 44·24	+1·24	+26 37 50·5	+10·2	G, Y
105	5 02 58·65	+1·25	+26 54 32·1	+10·3	G, Y
106	6 47 53·92	+1·95	+25 44 32·9	+ 6·0	Ay, G, Y
107	6 48 38·63	+1·95	+25 45 29·3	+ 6·0	G, Y
108	6 48 49·80	+1·96	+25 50 44·6	+ 6·0	G, Y
110	3 45 25·44	+0·46	+24 10 51·1	+ 8·5	Ay, G, Y
111	3 46 00·29	+0·47	+24 08 58·9	+ 8·5	Ay, G, Y
112	3 46 31·49	+0·47	+24 17 47·5	+ 8·5	G, Y
114	3 47 30·49	+0·47	+24 19 17·0	+ 8·5	G, Y
127	3 43 33·51	+3·48	+24 05 09·1	+14·9	Ay, G, Y
128	3 43 03·12	+3·49	+24 19 01·3	+14·8	G, Y
129	3 43 27·66	+3·49	+24 23 09·2	+14·8	G, Y
130	3 45 25·44	+3·47	+24 10 51·1	+14·7	Ay, G, Y

Ab = Abbadia 1900.
Al = Albany 1900.
Ay = Albany 1910.
B = Bonn 1925.
G = Greenwich 1910.
Y = Yale photographic.

University of Birmingham Observatory,
Edgbaston, Birmingham :
1935 *October* 8.

Errata

M.N., **95**, No. 8 (June), p. 640, *for* Nova Aquilæ (1895) *read* Nova Aquilæ (1925).

M.N., **95**, No. 8 (June), p. 705, Table I, line 14 of Multiplet column, *for* $z^4P^{\circ}_{\frac{1}{2}} - e^4P_{1\frac{1}{2}}$ *read* $z^4P^{\circ}_{\frac{1}{2}} - e^4D_{1\frac{1}{2}}$.

LIST OF ADDITIONS

TO THE

LIBRARY OF THE SOCIETY

1934 AUGUST 1 TO 1935 JULY 31

Serial Publications received by exchange in the regular course, and Reprints of Papers published in some of these Serials, are not included in this Annual List.

Unless otherwise indicated, the donor is the author or the Institution concerned.

An asterisk (*) indicates that the work is an excerpt.
A dagger (†) indicates that the work has been purchased.

Algiers, Observatoire :
——: Carte photographique du Ciel. Zone +11°. (6 Charts.)

——: Catalogue photographique du Ciel. Tome IV, suite du fascicole B.
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*Monthly Reports and Annual Report for the year 1934.
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8vo. Paris, 1934

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8vo. Bangalore, 1934–35

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†Tafeln zur theoretischen Astronomie. Zweite Auflage neu bearbeitet von Gustav Stracke. 4to. Leipzig, 1934

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†Geschichte des Fixsternhimmels. Abteilung I, Band 21.
4to. Karlsruhe, 1934

Band 21. 20^h Rektaszension.

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Veröffentlichung. Geschichte und Literatur des Lichtwechsels der veränderlichen Sterne. Zweite Ausgabe, enthaltend die Literatur der Jahre 1916–1933, von R. Prager. Band I. 4to. Berlin, 1934

Band 1. Andromeda—Crux.

Bordeaux, Observatoire :
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The Natural Logarithm.
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[Brahe (Tycho)] :
†Collection of twenty-eight sixteenth- and seventeenth-century tracts dealing with observations of Tycho Brahe's New Star of 1572 and the Comet of 1577. 4to. *v.l.*, 1573–1605

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(*British Association Tables Committee.*) 4to. London, 1934

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†Brunt (David) :
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Astronomische Abhandlungen, Band I, Nos. 3, 4.
8vo. Budapest, 1934–35

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(*Cambridge University Press.*) 8vo. Cambridge, 1934

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——: Memoirs. No. 4. 4to. Canberra, 1934

No. 4. C. W. Allen, Atmospheric potential gradient observations.

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Intensity of quartet lines in the arc spectrum of copper.

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Storia della Università di Catania, dalle origini al giorni nostri. Scritta da Michele Catalano, Matteo Gaudioso, Guiseppe Paladino, Guido Libertini, Gaetano Curcio, Carmelina Naselli. Quinto Centenario dell'ateneo di Catania. 8vo. Catania, 1934

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Collection Ant. W. M. Mensing, Amsterdam (now in Chicago, Illinois). Old Scientific Instruments (1479–1800). Catalogued by Max Engelmann. I, II. 2 vols. 8vo and 4to. Amsterdam, 1924

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II. Plates.

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(*F. J. M. Stratton.*) 8vo.

***Contributions à la théorie des effets de latitude et d'asymétrie des rayons cosmiques. I, II, III.**
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III. G. Lemaître, Trajectoires périodiques.

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Resultados. Vol. 25. 4to. Córdoba, 1934

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†Il Cielo e le sue Meraviglie. Atlante di 150 Tavole. Riproduzioni di fotografie celesti ottenute con i più grande telescopi moderni.
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	II.		6^h 12^h	122–245.
	III.		12^h 18^h	246–366.
	IV.		18^h 24^h	367–500.

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5. Diagrams or other illustrations accompanying Papers should be sent in a state suitable for direct photographic reproduction. It is preferable that diagrams should be drawn on a larger scale than required, in Indian ink on white paper, all lines, etc., being sufficiently bold to bear the reduction required. Any lettering should be written in pencil, that it may be re-drawn to the proper scale.

6. The attention of authors is particularly directed to the rule of the Council that when the cost of alterations to proofs exceeds 5 per cent. of the cost of setting up the type of a Paper, the excess must be borne by the author.

7. The Council has decided to destroy all MSS. of Papers presented to the Society which remain in their possession after the expiration of twelve months from the dates of publication. Authors who desire to recover their MSS. after that interval may do so if previous notice is given.

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